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FRUIT GROWING

BY

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PREFACE

It is, I think, rather generally agreed that during the past few centuries the thinking of the scientist has been more effective than has that of most other scholars. This may be largely because his thinking has been closely associated with actual experience in the laboratory. His teachings, also, seem to have been effective because the student has been permitted to test them in the laboratory. In pomology classrooms, and even in field laboratories, such learning by experience is possible only to a very limited extent. On account of the long life of the trees, experiments cannot be followed to completion. Merely pruning a college orchard will give the student little information as to the responses of trees unless he keeps records during all the time in which the behavior of the trees may be influenced by that treatment. Under some conditions the effects of a single pruning may not all be seen in ten years. The student can at best see only a part of the response and may be misled. In fact, it is impossible for the teacher during his lifetime to learn enough by actual experience to supply material for a course in pomology. He must depend in large part upon the evidence supplied by the experience of other workers with experimental trees and upon evidence suggested by his knowledge of the general nature and responses of plants; in the main, evidence that the student cannot test in the laboratory. The student must accept rather blindly the teacher's interpretation of the evidence, unless he is himself made acquainted with the sources of evidence and with the difficulties involved in its interpretation. It is with a desire to be of service to teachers in acquainting their students with the sources of knowledge and training them in the evaluation of evidence that this book has been written.

In its preparation, the greatest stress has not necessarily been placed where I would place the greatest stress in pomological research. I believe that the greatest emphasis in research should be placed upon studies of the physiological and chemical bases of orchard practices. However, since our physiological and chemical knowledge is far too incomplete to furnish a safe guide for practice, I have tried generally to start with the practical problem in the orchard; studying the evidence concerning it as furnished by experience, by rather superficial studies such as field experiments, and by more fundamental research; looking for agreement or disagreement among these classes of evidence. An effort has been made to show where help toward the solution of practical problems might be derived from fundamental studies; but when a critical examination of such physiological and chemical evidence seemed to require such lengthy treatment as to confuse, rather than to clarify, a discussion of practical problems, I have merely suggested what seemed to me to be the truth in such fundamental regards, and have assumed that the student will obtain more detailed fundamental knowledge by taking courses in different fields of plant science and in chemistry. In citing literature in such fields related to pomology, I have not attempted to follow historical development. Rather I have cited, in the main, recent treatments of the subject by specialists. I have assumed that in such sources the student will find references to recent and earlier literature.

Much attention is given to the special responses of different kinds of fruit trees, even at the risk of a considerable amount of repetition; for it is nearly always from such details, rather than from general knowledge of responses common to all kinds, that decisions as to practices must be made. Further, it is hoped that by such detailed study the student will come to have a better understanding of the principles involved, their limitations and their interrelations. It is hoped that he will be led to appreciate the unwisdom of arriving at conclusions about living things by reasoning from a single principle, even if that principle be well established.

In discussing a problem, an effort has been made to follow the evidence to some kind of conclusion. It seemed that a suggested opinion might tend to clarify the problem even though the opinion might later be found to be wrong. However, I have tried not to write in an oracular way, but so to present the evidence as to lead the students away from the view that what is printed in a textbook is to be learned and accepted without question.

This work has not been done hurriedly. It has been in progress nine years, and has been completely written four times; yet it has been necessary to seek evidence concerning some of the problems from so many different fields that errors certainly cannot always have been avoided. Further, in the present state of our knowledge, opinions must be based partly upon the results of daily contact with trees; and workers in environments in which I have not had such contact will know from their unpublished experiences that some of the conclusions as to environmental responses of the different species are wrong.

With all the chapters, I have had advice from Professors A. J. Heinicke and O. F. Curtis, of Cornell University; and Professor E. L. Overholser, of the University of California. Professors T. L. Lyon, L. H. MacDaniels, D. B. Carrick, W. M. Wilson and H. H. Love, of Cornell University; Professors W. L. Howard, A. H. Hendrickson, J. P. Bennett, W. P. Tufts, E. B. Babcock, F. T. Bioletti, W. H. Dore, H. J. Webber, and W. P. Kelley, of the University of California; and Professor E. C. Auchter, of the University of Maryland, have given advice for some chapters. Professor E. J. Kraus has given valuable information both in conferences and in letters; but he has seen none of the manuscript. To each of these men I am very grateful. In fairness to them it should be said that their help was not of such a nature that they could be held responsible for any of the errors that will be found.

Berkeley, California
May, 1925

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FRUIT GROWING

⁂

INTRODUCTION

It is the purpose in this book to study the responses of fruit trees or plants, and the responses of fruits as living organisms, to their environment. The responses of trees or plants to the necessary cultural practices, and of fruits to the necessary practices in harvesting, transportation, and storage will be stressed. It will be assumed, however, that any knowledge concerning the behavior of fruits or fruit plants may be found to be of value in the solution of orchard problems.

Of great practical importance is the response of fruits and fruiting plants to injuries from fungi, bacteria, or insects. A careful study of these problems, however, requires an intimate knowledge of the behavior of the organisms causing the injuries; and discussion of them is omitted, since it can be done better by plant pathologists and entomologists, who have such intimate knowledge concerning the organisms involved.

In getting at the truth as to the best orchard practice, we may study the methods of the successful growers, or perform field experiments with the trees, or we may reason from our knowledge of the fundamental nature of the trees.

The reliability of the experience of fruit growers. The practices of farmers and of fruit growers result from the experiences of very many. Assuming, as we must, an intelligence as great as that of the average man, it seems probable that, when so many may be trying different methods, some one will find the most desirable practice. It is doubtful, however, whether the fruit grower can be as certain as can the farmer growing annual crops that his practice is the best for his conditions. The difference in yield of adjacent plots of trees receiving like treatment is very great, yet the grower is likely to be comparing, not adjacent plots, but his orchard with that of his neighbor, or one orchard with another on the same farm. He does not have the same experience repeated many times. The potato grower will see his crop planted, grown, and harvested each year. The apple grower in the northeastern part of the United States must wait thirty-five to forty years from the time of planting and early training of his trees before he sees them bearing maximum crops. Instances are found where a practice of fruit growers of an entire community is apparently wrong.

There is in favor of the practices of growers, however, the fact that we know from experience through a considerable number of years what results may be expected. It is not impossible that a new practice might give better results during a few years, but that through a long period of years, with varying weather and market conditions, it would not be desirable. It seems wise, then, not to oppose generally accepted practice until there is conclusive evidence against its wisdom. Certainly, with the wide range of error that we shall see obtains in field experiments with trees, one should be slow to conclude from brief experience with such experiments that a widely accepted practice is wrong.

The reliability of field experiments. It does not seem necessary to discuss here all the sources of error involved in the different kinds of experiments with trees; they will become evident as we proceed with the different problems. There are, of course, the differences due to whatever bud variations there may be, and probably larger differences caused by the fact that, with apples at least, the seedling stocks used vary widely in vigor of growth; possibly not all of them are even of the same species. Then an injury to a tree may cause accumulating differences as it grows older. Under pruning experiments we shall see that a difference in the number of branches with which the tree starts may affect the growth and yield through a considerable number of years. The greatest source of error, however, arises from the fact that so few individuals grow upon an acre. Of course the larger the number of individuals in a plat of a given size, the smaller the error due to individual variation. Yet, if the plots must be very large in order to include a representative number of individuals, the error due to differences in the soil of different plats becomes exceptionally large; and trees respond to differences in soil, particularly differences in soil depth, more than do most other crops.

Batchelor and Reed (2) have published the results of studies as to the variation in yield of orange, lemon, walnut, and apple trees. Some of the orchards were under irrigation; and so the error due to variations in water supply was probably below the average. Only orchards in which the soil seemed very nearly uniform were used. When a tree was rendered abnormal by disease or other cause that was apparent, there was substituted for it in the calculations the average yield of the eight adjacent trees. The records are, with a few exceptions, for yields during the years 1915 and 1916. The following table summarizes their results as to experimental error involved:

TABLE 1. SHOWING THE MEASURES OF VARIABILITY IN YIELD OF FRUIT TREES

KIND OF FRUIT	CROP	ACREAGE TO THE TREE	NUMBER OF TREES	MEAN YIELD TO THE TREE (lbs.)	STANDARD DEVIATION (lbs.)	COEFFICIENT OF VARIABILITY	PROBABLE ERROR	
							Lbs. to the tree	Per cent of mean
Navel orange (Arlington)	1915	0.011	1000	137.6±1.2	54.42±0.82	39.55±0.68	37	26.67
Navel orange (Antelope Heights)..	1916	.011	495	186.2±1.7	55.33±1.19	29.72±0.69	37	20.05
Valencia orange...	1915	.011	240	246.3±4.3	97.84±3.01	39.72±1.40	66	26.79
Eureka lemon.....	1915	.013	364	270.7±2.9	81.38±2.03	30.06±0.81	55	20.28
Seedling walnut...	1915	.057	280	99.8±1.9	47.77±1.36	47.86±1.64	32	32.28
Seedling walnut...	1916	.057	280	77.6±1.7	41.94±1.19	53.91±1.92	28	36.36
Seedling walnut (average).......	1915 and 1916	.057	280	86.4±1.6	40.10±1.14	46.41±1.58	27	31.30
Jonathan apple....	1914	.011	224	303.9±5.6	125.30±4.00	41.23±1.52	85	27.81

Three terms are used in this table as measures of variability: standard deviation; coefficient of variability; and probable error.

Average deviation is sometimes employed instead of standard deviation. The mean (m) of a series of readings is determined, and the deviation (d) of each reading, from the mean. Then the average deviation is obtained by dividing the sum of these deviations (added without regard to signs), by the number of readings. To determine standard deviation the individual deviations are squared. The sum of these squares is divided by the number of readings (n), and the square root is extracted. By this method greater weight is given to the large deviations; the formula being

$$\text{Standard deviation} = \sqrt{\frac{\Sigma\, d^2}{n}}$$

A good illustration may be taken from Wood and Stratton's (17) determinations of dry matter in mangel roots.

TABLE 2. SHOWING METHOD OF CALCULATING STANDARD DEVIATION

PERCENTAGE OF DRY MATTER	d	d^2
14.2	1.2	1.44
16.6	1.2	1.44
13.8	1.6	2.55
11.3	4.1	16.81
17.5	2.1	4.41
15.0	0.4	0.16
16.8	1.4	1.96
17.2	1.8	3.24
15.1	0.3	0.09
16.6	1.2	1.44
Average....15.4		$\Sigma\, d^2 = 33.55$

$$\text{Standard deviation} = \sqrt{\frac{33.55}{10}} = 1.83$$

The coefficient of variability (c) expresses the deviation in proportion to the mean. The formula is

$$c = \frac{100}{m} \times \text{standard deviation}$$

Using the above figures it would be

$$\frac{100 \times 1.83}{15.4} = 11.9$$

Perhaps the most widely used measure of the reliability of results is the probable error. The probable error of the mean may be derived from the standard deviation as follows:

$$P.E.M. = \frac{0.6745}{\sqrt{n}} \times \text{standard deviation}$$

In the above example this would be:

$$\frac{0.6745 \times 1.83}{\sqrt{10}} = \pm 0.391$$

Where the number of readings is rather small, Bessel's formula seems better, since by it the probable error is larger. This formula for the probable error of a single reading is:

$$P.E. = 0.6745 \sqrt{\frac{\Sigma d^2}{n-1}}$$

Using Σd^2 of Table 2, it would be:

$$0.6745 \sqrt{\frac{33.55}{9}} = \pm 1.29$$

This gives a measure of the reliability of any one result. The probable error of the mean ($P.E.M.$) is determined by dividing the probable error of a single reading by the square root of the number of readings, thus:

$$\frac{1.29}{\sqrt{10}} = \pm 0.41$$

If one is not interested in the probable error of a single reading, time can be saved by using the formula:

$$P.E.M. = 0.6745 \sqrt{\frac{\Sigma d^2}{n(n-1)}}$$

in calculating the probable error of the average. The probable error of the difference between two results is the square root of the sum of the squares of the probable errors of the two results.

The probable error is based on the law of probability, which is highly dependable only for large numbers of readings. With the small numbers of readings generally involved in field plats, it is useful mainly as an indication that a difference is certainly not significant. When few readings are involved, it seems that we should admit the insignificance of a difference that is small in proportion to the probable error, more readily than the significance of a difference that is rather large in proportion to the probable error; in the former case the experiment should certainly be repeated, and in the latter case it might be wise to repeat it.

When the number of readings is sufficiently large, there is an even chance that the true answer does not vary from the results obtained by an amount greater than the probable error; and, of course, an even chance that it does so vary. Differences are not considered to be of much significance unless they are at least three times the probable error. The following table is taken from Wood (16):

TABLE 3. SHOWING THE RELATION OF THE PROBABLE ERROR TO THE RELIABILITY OF RESULTS

DIFFERENCE FROM THE MEAN IN TERMS OF PROBABLE ERROR	ODDS AGAINST SUCH DIFFERENCE OCCURRING UNDER UNIFORM CONDITIONS
1.00	1 to 1
1.25	3 to 2
1.44	2 to 1
1.71	3 to 1
1.90	4 to 1
2.00	9 to 2
2.05	5 to 1
2.50	10 to 1
2.93	20 to 1
3.00	22 to 1
3.20	30 to 1
4.00	140 to 1
4.90	1000 to 1
5.00	1350 to 1

We must not misinterpret this table. Thus, let us say that we have a single plat of trees receiving some kind of fertilizer, and its yield is greater than that of an adjacent check plat by three times the probable error of the difference, as calculated from the yields of individual trees in the plats. We could hardly assume that the odds are about twenty-two to one that the difference is not due to other influences than the difference in treatment. In such an experiment, where only one plat receives each treatment, the probable error may tell little as to the variability of the soil. The trees are so far apart that the soil in all of one plat may be very different from that in another; sometimes without there being great variability within a plat. And the probable error in such an experiment takes into account only the variability within a plat.

The error due to variation in the soil is great even in orchards where the soil appears very nearly uniform. To reduce this error, it is necessary to have a number of plats receiving each treatment. Thus, Batchelor and Reed found the coefficient of variability of an average plat of sixteen adjacent trees to be 22.58, while for four plats of four trees each it was but 9.29. This was in a soil that seemed uniform. The following table gives probable errors determined by these workers with Jonathan apples:

TABLE 4. PROBABLE ERROR WITH JONATHAN APPLE TREES WHEN THE EXPERIMENTAL AREA IS ARRANGED IN UNITS OF DIFFERENT SIZES

PLAT	EXTREME YIELDS PER PLAT (lbs.)	MEAN YIELD PER PLAT (lbs.)	PROBABLE ERROR PER PLAT (per cent of mean)
16 trees adjacent..................	3000 to 6500	4864±176	±13.49
2 units of 8 trees................	3900 to 6100	4857±115	± 8.90
4 units of 4 trees................	3800 to 5400	487±174	± 5.69

The probable error is reduced from ± 13.49 to ± 5.69 by having sixteen trees in four plats distributed over the experimental area rather than in one block. It is interesting to note, with two adjacent plats, even in apparently uniform soils, how large a difference must be before it can be considered significant. Thus, when the probable error is ± 13.49, that of the difference is $\pm 13.49 \times \sqrt{2} = \pm\ 18.89$. A difference to be significant should be at least three times the probable error, or about 56.67 per cent of the yield of the check plat with which the treated plat is compared. With four distributed plats to each treatment, differences to be significant would have to be 25 to 30 per cent of the yield of the checks; and considerably larger in some soils and with some kinds of trees.

Sometimes, however, the probable error, as calculated by Bessel's formula, is so large that differences obviously significant are made to appear insignificant. Thus, Love and Brunson (10) cite an example in which one variety of oats yielded more than another in each of nine years; yet the variation in yield from year to year was so great that the probable error, by Bessel's formula, of the average annual yield of each variety was so large that the odds were only 4.3 to 1 that the difference in yield was due to a greater yielding capacity of one of the varieties. The feature that is not taken into consideration by Bessel's formula is the pairing. Each year both varieties were influenced alike by the conditions that increased or decreased the yield. There might be such pairing in field experiments with trees. If the plats extended through soil that was very poor for trees and through soil in which the trees grew exceptionally well, significant results might be obtained if in all the treatments there were the same numbers of trees in each kind of soil; that is, if the trees were paired. Yet by Bessel's formula all the variation among the trees in each plat would be included as if there had been no pairing.

One anonymous writer, signing as "Student" (13), has described a method by which the effect of pairing is taken into consideration. By this formula each pair is considered separately, and the algebraic sum of the gains or losses is divided by the number of pairs to obtain the average gain due to a treatment. This average is divided by the standard deviation; and from the quotient (Z) the probability (P) is learned by reference to the tables in the original paper published by the author (13 and 14) or to Pearson's *Tables for Statisticians and Biometricians.* Table 5 is from the paper by Love and Brunson and is a record of yield of corn on manured and unmanured plots in different fields.

TABLE 5. THE EFFECT OF MANURE ON THE YIELDS OF CORN IN DIFFERENT FIELDS. PROBABILITY CALCULATED ACCORDING TO "STUDENT'S" METHOD

NO. YEARS AVERAGED	FIELD	YIELDS TO THE ACRE		
		No treatment (bu.)	Manure (bu.)	Gain or loss (bu.)
4	Aledo	66.5	79.1	+12.6
4	Dixon	42.3	58.5	+16.2
5	Joliet	32.0	39.5	+ 7.5
4	Kewanee	59.0	68.2	+ 9.2
4	La Moille	52.5	64.4	+11.9
4	Mt. Morris	46.9	60.3	+13.4

Mean gain........11.8

(Standard deviation) = 2.82

$$Z = \frac{11.8}{2.82} = 4.18$$

$P = .9998$

$1. - .9998 = .0002$

Odds = .9998 to .0002 = 4999 to 1.

The fact that, in every field, there is an apparent gain in the manured plats suggests strongly that the differences are significant; and by "Student's" formula, in which the pairing in different fields is given weight, the odds are very great that the differences are due to the manure. Yet so great is the variation in yield in different fields that, when the probable error is calculated by Bessel's formula, the odds are but 8.3 to 1 that the differences are due to the manure.

The odds are large in this series partly because all the figures in the gain or loss column are positive. It should be emphasized that it is the algebraic sum of the gains and losses that is divided by the number of pairs to obtain the mean gain. If in, let us say, the last field there had been a loss of 13.4 bushels, the mean gain would have been 7.33. Standard deviation would have been larger; for the signs must be considered in determining the individual deviations. The odds would, therefore, have been much smaller.

If these results were for the yields of trees in plats so arranged that each check tree in each kind of soil was adjacent to a treated tree, "Student's" formula would give the better measure of the dependableness of the results. However, this formula should not be used except under conditions where there is naturally a pairing of plats or of individuals. If the trees were in square plats, it would not be permissible to select the weak trees in the check to compare with the weak treated trees; unless the yield records of all the trees had been kept during a preliminary period and the plats had been so arranged as to include an equal number of low, medium, and high yielding trees. When only a few readings are involved, and the differences, though small, are the same for each pair, odds, as determined by "Student's" formula, will sometimes be erroneously high.

Batchelor and Reed emphasize a very important precaution that should always be observed in laying out a series of field experiments. They suggest that, during a period of from two to four years before the plats to receive the different treatments are definitely located, the whole field should be kept under uniform treatment, and records should be kept of the yield of each tree. Then plats could be so arranged that the average tree yield during this preliminary period would be about the same; or else the yield of each plat during this preliminary period could be used in weighting the results obtained from the plats receiving the different treatments. It seems that this refinement in our methods certainly must be adopted if field experiments with trees are to give results sufficiently accurate that differences of fifteen to twenty per cent may be depended upon.

These workers found that the coefficient of variability was appreciably reduced as the number of trees to the plat was increased from one to eight; but there seemed to be slight additional reduction as the size of the plats was increased to numbers above eight trees. They seemed to find also that the shape of the plat makes little difference as to accuracy. They studied the use of different formulas in comparing a given treated plat with the checks, where a series of evenly distributed check plats are used. Not all of their formulas need be discussed here. The most reliable results seemed to be obtained with the simple formula $2/3\ C_1 + 1/3\ C_2$, when C_1 is the check nearest the plat considered and C_2 is the next nearest. It seems that the method of using the checks will depend upon the nature of the soil variations and the nature of the experiment.

They suggest also that the variability is decreased but slightly, with the navel orange or the Rome Beauty apple, by combining the results of several years instead of using those of only one year. With the Rome Beauty apple, they were using the results of Hedrick (622) with young trees. The calculations of Batchelor and Reed are given in the following table:

TABLE 6. COMPARATIVE VARIABILITY OF YIELD OF YOUNG ROME BEAUTY APPLE TREES THROUGH A PERIOD OF SEVEN YEARS

CLASS	COEFFICIENT OF VARIABILITY OF THE YIELD				
	1 year (1910)	2 years (1909, 1910)	3 years (1908, 1909, 1910)	4 years (1906, 1908, 1909, 1910)	7 years (1902, 1903, 1905, 1906, 1908, 1909, 1910)
Individual trees....	37.3±5.2	33.6±4.6	32.5±4.4	32.2±4.4	34.0±4.7
Plats of five trees each............	18.5±2.9	16.8±2.6	18.1±2.8	18.2±2.8	21.7±3.4

However, Rome Beauty bears heavily and rather uniformly. If a different variety had been used, or if more of the trees in some plats than in others had borne their heaviest crop in, let us say, the odd years, variability might have been reduced by increasing the number of years in which records were taken. The crop failure in 1904 would tend to cause all the trees to have their heaviest bearing year the same year; that of 1907 reversing the order as to years, but promoting the tendency for all the trees to bear heavily in the same year.

Weather conditions of a section might have much to do with the dependability of one or two seasons' results. Further, it is often necessary to keep records of yields through a long period of years in order to determine the cumulative effect of a treatment on the trees.

It is often desirable to study the effect of a treatment on growth as well as yield. Several methods of measuring growth have been employed. The annual twig growth is sometimes used. This should be reasonably accurate if the measurements were taken every year through which the experiment was continued and if all trees were pruned alike. It is doubtful whether one year's records would be satisfactory, since, if the tree should make a large twig growth in one year, it might, for that reason, make a smaller one in the next. A tree that is prevented, by some influence such as sod, from making a large growth in one very favorable year, might make more twig growth in the following year than it would average through a period of years. In pruning experiments records of the total or of the average twig growth may give useful information; but they give no measure of the total growth of the tree. For, by pruning, the number of growing points and the growing area are reduced. And a pruned tree will often show an increase in twig growth when the total amount of growth made has been reduced; if the tree had not been pruned, a layer of new wood would have been formed over all the wood removed in pruning. Further, twig measurement is so laborious that not many trees can be used if such measurements are to be obtained for all of them. And we have seen that it is necessary to have a considerable number of trees divided into several plats receiving each treatment, if a dependable degree of accuracy is to be obtained. It seems probable, therefore, that twig measurements cannot form a leading part of the records of field experiments.

The diameter of the trunk is the most common growth record kept, and under some conditions it gives rather accurate results. Thus, Tufts (903) found a correlation as high as 0.92 between the diameter of the trunk and the weight of the top of young peach trees. This was in California where the growing season is long; and the trees were under uniform treatment. We shall see that both severe pruning and fertilizing with nitrogen tend to cause the tree to make a larger proportion of its growth as top growth. This of course will affect the relation of the trunk diameter to tree weight. Heinicke (8) found that, while the coefficient of correlation of trunk girth and weight of trees is high, yet, unless large numbers of trees of nearly uniform size are used, small differences in growth cannot be measured accurately by trunk girth alone. Where it is desirable to know the effect of a treatment on growth it is generally best to plant the trees closely and to remove and weigh them.

This is true not only because the actual weight is the only final measure of growth, but also because the close planting reduces the error due to variations in the soil.

It is evident that accuracy is not obtained merely through care in weighing the fruit or measuring the growth. In fact, such care, although its omission is generally inexcusable, is one of the less important features of accurate field experimentation. From the works of Batchelor and Reed it seems that merely estimating the crop on the trees in an experiment containing four systematically distributed plats uniformly treated, and as many checks, would give more dependable results than could be obtained by the most accurate measurements in case of a single plat with a single check.

The survey method of research. The fact that rather large errors in record-taking may not reduce the accuracy of the results, if the number of records is very large, is made use of in the survey method that is being quite widely applied in the study of farm problems. Spillman (12) cites an instance that illustrates well the greater importance of large numbers of readings as compared with accuracy in a few readings. At Penn Yan, New York, precipitation records have been kept for sixty years, and the average to the year is 29.113 inches. If, instead of the actual rainfall for each year, the nearest multiple of 10 had been used, as 30 for any number between 25 and 30, and 20 for any between 20 and 25, the average rainfall for the sixty years would be 28.667 inches. This is an error of 1.532 per cent of the true answer, assuming that 29.113 is the true answer. If the sixty-year period is divided into six periods of ten years each, the variation from the sixty-year mean is 3.24, 7.51, 2.95, 7.24, 2.94 and 3.52 per cent respectively. In no ten-year period was the actual average as near to the sixty-year average as was the approximate sixty-year average obtained by using the nearest multiple of ten inches for each of the sixty years.

In making surveys, each farmer is asked questions as to the treatment a field has received and the results obtained. The farmer may not remember the exact amount of manure applied to a field, or the exact yield; but if enough farmers are visited, the answer will be too high about as often as it will be too low; and the average will probably be near to the average that would have been obtained if careful records had been kept. It should be borne in mind, however, that the errors in record taking are probably not among the more important errors involved in this kind of work. Variations in soil and in other features that determine yield in an orchard are so great that comparing two orchards on different farms managed by different men would almost certainly give less dependable results than comparing two normal appearing adjacent trees in the same orchard. Probably very many more orchards in a survey than trees in a field experiment would have to be used in order to obtain significant data in comparing orchard practices, even when only unweighted variability is considered. And there may be other sources of error. Warren (1156) suggests that there might be correlations that would cause misleading results. Thus, if one were trying to find whether or not cultivation in the orchard gives better results than sod, one might encounter a source of error in the fact that more of the cultivated than of the uncultivated orchards are sprayed; and the larger yields on the cultivated orchards might be due to the spraying rather than to the cultivation. However, when the records were sorted in such a way that only sprayed orchards or only unsprayed orchards were considered, he found that the comparative results were not greatly changed. There is great difference in the effectiveness of the spraying by different orchardists, and the cultivated orchards may have been owned by men who sprayed the more effectively. Correlations of this nature, it seems probable, would bring greater errors into studies as to the effect of fertilizers or cover-crops than as to the effect of cultivation. The orchardist who is prosperous on account of the effectiveness of his spraying or the excellence of his soil, would be more likely to buy fertilizers, or expensive seed for leguminous cover-crops, than one who has less available money. With pruning or thinning, it seems doubtful if the farmer's memory would supply enough data for results from surveys to be of great value. The effect of pruning is determined largely by the amount of wood removed. Certainly the farmer could not remember, or even estimate very closely at the time of pruning, the amount of wood removed; yet other comparisons would be of little value unless the severity of the pruning averaged the same.

Perhaps the greatest defect in the survey method is that it lumps together large numbers of conditions so that the result obtained can seldom be applied to any specific set of conditions. If in a survey of one half of a county it were found that the use of fertilizers had increased the yield, it would not be certain whether this increase had come altogether from orchards in the less fertile soils or whether, in all of the soils involved, trees would respond to applications of fertilizers. With crops like grains or potatoes, it is possible that the plantings might be classified as to soil and enough farms studied in each soil type to give dependable results. This would very seldom be true for trees; and results from surveys, in so far as orchard cultural practices are concerned, must as a rule be rather general, while what we need to help the growers is information that can be applied to a specific set of conditions. However, experiments are sometimes undertaken with the hope that the information obtained will solve the problems of a particular district; and such experiments may be more wisely planned if they are preceded by a survey of the district, the survey being useful not so much for the averages made as for the different conditions and responses found in different orchards.

Deducing rules as to practice from knowledge of fundamental principles. A statement that a practice is advisable because of some principle of plant behavior seems very convincing to many people, particularly to students. However, conclusions deduced from biological principles may not always be as dependable as deductions from mathematical principles. The responses of the plant are determined by so many environmental conditions that it will be long before the most general principles of plant behavior can be applied with certainty to all important plants under all probable environmental conditions. When a man says that a certain cultural method is advisable because of a certain principle of plant behavior, he may be unaware of the modifying influence of one or more other principles that may not be so well understood. Of course, the reason the use of biological principles as guides to practice involves some danger is because of the incompleteness of our biological knowledge; and we hope that eventually that knowledge will be so complete as to be a dependable and far-reaching guide to practice. Not until we have such comprehensive and detailed knowledge of plant responses can we safely advise growers concerning new problems that are constantly arising; and results of field experiments that are not planned and interpreted in the light of such knowledge cannot be used except under conditions nearly identical with those under which the experiment was conducted.

Much of the discussion in this book will not directly concern practices in fruit growing, but will deal with evidence concerning the nature of the responses of fruit trees. This plan will be followed in order that evidence as to best practices, furnished by the experience of growers and by field experiments, may be examined as to its agreement with basic knowledge of plant life. It may be that, by thus making use of these three sources of knowledge, we can reach a fairly close approach to the truth concerning many orchard problems.

CHAPTER 1

SOME GROWTH HABITS AND FOOD RESERVES OF FRUIT TREES

It is not the purpose to enter into a discussion of the physiology of growth, but rather to describe some growth habits of the plants with which we are concerned. It is well known that the tree increases in size both from terminal root and stem growing points and by increase in thickness due to cambial growth.

Growth of new shoots. For convenience in this book, with deciduous trees the term "shoot" will be used for a growth of the current season while it still contains its leaves; after leaf fall and until new growth has started from it in the succeeding year, it will be called a "twig." With evergreen trees the term "shoot" will be used for a growth less than one year old containing leaves of one season's development.

The term "vigor" will be used to describe a condition of growth with shoots. By "vigorous growth" will be meant growth that tends to continue late in the season, the shoots being relatively long and the leaves large and of a rather deep green color for leaves of the variety concerned. With trees of the same size having like treatment, the most vigorous tree will make the greatest total growth. However, a young tree or a severely pruned tree will make a more vigorous shoot growth than it would make if it were older or unpruned; but a smaller total growth. That is, with the older tree or the unpruned tree, there is less shoot growth from any single growing point; but, because of the greater number of growing points and the greater amount of wood around which a new layer of wood is formed, the total amount of growth is greater than with a younger tree or a severely pruned one.

When the tree is young, shoot growth may continue during most of the summer. As it grows older, shoot growth ceases earlier each summer. An age is finally reached at which very little shoot growth is made. Thus, Gourley (152) found, in New Hampshire with apple trees thirty-one years old, that practically all shoot growth is made during a period of about twenty-five days — in that climate, about the last five to ten days of May and the first fifteen to twenty days in June. Such a condition of little shoot growth is, of course, reached later in life with trees growing under the more favorable soil and climatic conditions, but is always eventually reached. This is not true of fruits like the raspberry and the blackberry with which new shoots grow from the roots every year. If plantings of these come to be weak as they grow old, it is because of disease or of unfavorable conditions developing in the soil, and not because of the increasing size of the top, as with trees or with gooseberry and currant plants.

The length of the growing period, particularly for young trees, is, of course, influenced by the nature of the season. At Ithaca, New York, apple trees planted in 1911 ceased shoot growth and formed terminal buds about July 25th in 1916, August 29th in 1917, and June 1st in 1918. This represented a growing period of about seventy days in 1916, ninety-five days in 1917, and twenty days in 1918. If shoot growth is checked by dry or very hot sunny weather, it may be resumed again if rainy weather or weather favorable to low transpiration follows soon. With most deciduous kinds, such a second growth will be separated from the other by bud scale scars that are not so close to each other as those separating annual growth. Figure 1 shows at *a* such scars for second growth of apple twigs. It will be observed that lateral buds are found above and below the second growth scars, but not generally below the scars marking the beginning of the season's growth. If such lateral buds are found on the older wood, they are less prominent, being partly covered by new bark growth. After length growth has ceased, the shoots gradually go into

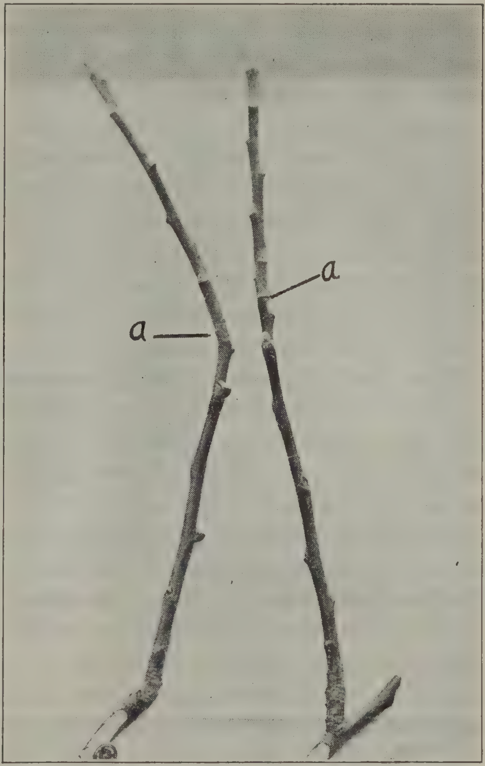

FIGURE 1. Showing at *a* the type of scars left when a new shoot growth has been made after the terminal bud had partly formed. The scars left by the bud scales at the beginning of a season's growth are shown at the base.

a condition such that they will not respond with second growth if weather conditions become favorable; that is, they gradually go into the rest period.

With the olive, as with some other evergreen species, the terminal of a shoot is not covered by bud scales during winter dormancy or between growing periods in summer. When growth is resumed, the leaves which may have been folded loosely over the end are not abscised, but grow to the size of normal leaves. Since there are no bud scale scars such as those shown at the base of the twig in Figure 1, and since the leaves of the previous season are retained, it is not always easy to distinguish growth of the current season from that of the previous year, unless there are fruits borne on the latter.

Some deciduous trees such as the apricot, in the climate of California, tend to have cyclic growth. That is, when the water supply is such that other kinds would make continuous growth, the apricot shoots will have in the season several growing periods. (With the apricot, there is no terminal bud; the terminal growing point being abscised at the end of each period and new growth starting from the most distal lateral bud.) Cyclic growth is common with citrous fruit trees and with a number of other tropical and subtropical kinds.

Reed (286, 287) has studied the nature of the growth rate of shoots of pears and of apricots in the climate of Riverside, California. With the pear the growth rate was similar to that of an autocatalytic reaction, being rather slow at first, then more rapid, and toward the end gradually slower. The curve is shown in Figure 2. With the apricot in that climate the initial period of slow growth, if present, was of shorter duration; but the measurements began when the shoots were ten centimeters long. He found with each growth cycle of apricot shoots a tendency for the rate of elongation to resemble the rate of an autocatalytic reaction. The same was true of the growth cycles of young walnut trees. It does not necessarily follow that growth is an autocatalytic reaction. In fact it would be expected that a record of the growth rate would form a curve similar to that in Figure 2. The growth should be slow at first because fewer cells will have been formed, to be in the process of elongation. Ludwig (221) found a similar growth rate for peach tree shoots at Clemson College, South Carolina. In a section where the temperature rise soon after growth starts is more rapid than at Riverside, or Clemson College, or perhaps where the rest period is more nearly ended when growth starts, the most rapid growth rate might be reached more quickly; but if measurements were taken often enough they would probably show an elongation rate slow at first, then more rapid and again slow as in Figure 2.

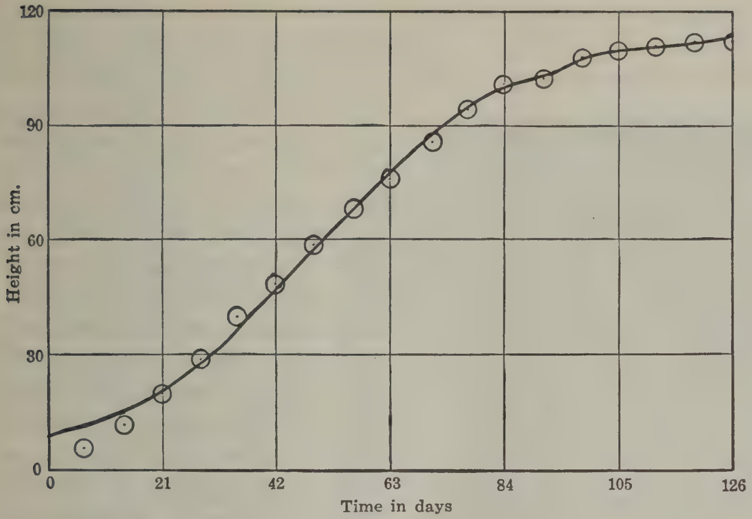

Figure 2. Growth rate of shoots of the pear tree. (After Reed.)

Generally it is only from rather vigorous shoots that lateral shoots form; and, even in the succeeding year, shoots from the lateral buds of the twig tend to be mainly near the distal end; or the longest ones are near that end. The longest shoot tends to be from the end bud of a twig. If that bud is removed the longest shoot tends to be from the bud left nearest the distal end. In other words, the end bud and lateral buds near the end seem to have the advantage in growth, and in some way they tend to inhibit growth from buds farther from the distal end. This inhibiting influence exerted by the terminal growth is much more striking with some varieties than with others and under some conditions of tree culture than under others. McCallum (861) seemed to find, also, that roots formed at the base of a cutting tend to inhibit root formation higher on the cutting; unless a notch is made when root formation will be above the notch. When a branch is bent downward the tendency (stronger with some kinds than with others) is for the most vigorous shoot to start from near the highest point on the curved branch, rather than from the terminal. This tendency for the strongest shoot growth to be near the distal end of the branch and for the strongest root growth to be at the base of the cutting or plant is known as polarity. A more extended discussion of polarity in its relation to the training of fruit trees will be found in Chapter 17.

Dormant buds. Some of the wood buds located on the twigs may remain dormant permanently, or until they are forced into growth by some stimulation, such as severe pruning of the part above. Such buds lengthen a little each year so that the growing point is at the surface of the bark. Figure 3 is of a dormant bud seven years old. When a branch has a large part of the end cut off, many new sprouts may grow at the cut end or back of it. With some kinds of trees such as the beech and the poplar, these shoots may be nearly all from adventitious buds in the callous growth beneath the bark at the end as shown at *a* in Figure 4; but with most kinds of deciduous fruit trees this does not seem to be true. In the spring of 1920 in the Cornell University orchard a large number of dormant buds on fruit trees, mainly Northern Spy apple, were marked and the branches cut back severely. During the following summer observations were made as to how many of the sprouts, if any, came from these dormant buds. Many sprouts grew from the branch stubs left but every one was from one of these marked buds. Many branches on peach trees were cut back to stubs and the dormant buds removed. No sprout grew on any of these stubs. I have known the buds to be killed on young peach trees stored beneath the soil during winter. Although the wood was uninjured, no shoots grew from these trees. In the spring of 1922 of 230 branch stubs of apple trees top-worked not a shoot was found that grew from callous tissue like that shown in Figure 4; but all grew from dormant buds or from spurs. The same was true of ninety-two such stubs on pear trees and of stubs on a number of plum trees.

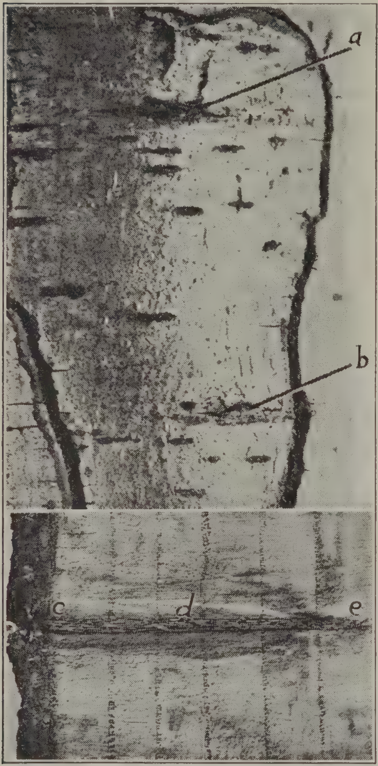

FIGURE 3. Showing at *a* and *b* openings in the bark over dormant buds and at the line *c*, *d*, and *e* the tissue developed crosswise to the grain of the sapwood as the dormant bud has grown, from its initiation in the original shoot at *e*, with each of six years of new layers of wood.

In the spring of 1920 a considerable number of Baldwin apple trees, three years from whip grafts and four to five feet high, were cut back to stubs about two feet high. On half of these stubs the dormant buds that were apparent were removed. On nearly all such trees a few new shoots grew. These never started more than three sixteenths of an inch from the center of the scar where a dormant bud or a branch had been removed. Many scars that were not near dormant buds had been made by cutting out small pieces of bark; but no shoot started from any of these. This observation suggests either that the tissue around a bud, or around the base of a twig or a branch, more readily forms adventitious buds than does other tissue or that there are, in the tissue around dormant buds or around the bases of twigs or branches, very small dormant buds that grew in the axils of the scales of the principal bud.

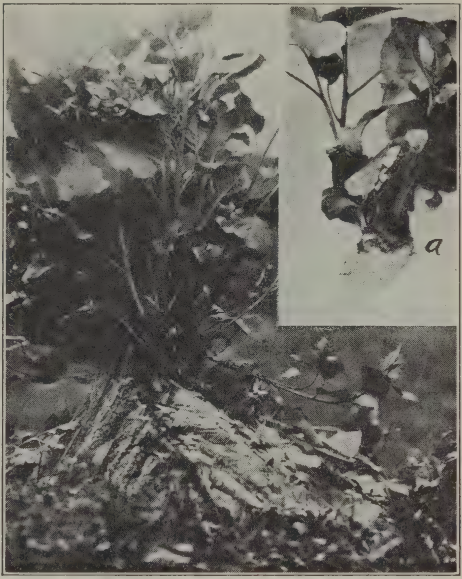

FIGURE 4. A clump of sprouts growing from adventitious buds in the callus-like new tissue between the bark and the sapwood of a poplar stump; at *a* is inserted a clump of the sprouts and a piece of the new callus-like tissue from which they grew.

The fact that most deciduous fruit trees do not readily form adventitious buds is of considerable importance in pruning. Thus, if with a beech or a poplar tree a stub were left new shoots would probably grow from adventitious buds in the callus at the end and the wound would be covered. However, with fruit trees shoots may grow from dormant buds rather near the end of such a stub, but never from callus at the very end. Often there is no growth whatever from the stub and it dies and rots back into the trunk or branch from which it protrudes.

Growth in thickness. Increase in thickness of tree parts is from the division and expansion of cambium cells. Figure 5, furnished by Professor L. H. MacDaniels (862), shows a section cut tangentially to the wood of the pear, so as to obtain a sheet of cambium cells. The smaller ones, dividing, form the medullary rays of the wood; and the larger ones, dividing lengthwise in the tangential plane, give the cells that, after differentiation, become tracheids, segments of the vessels, and other xylem elements, and those which after differentiation become the sieve tubes and other elements of the phloem. As the circumference of the wood increases, the number of cambium cells must also increase. Bailey (34) found that new cells of the long type shown in Figure 5 may, with some species, be formed by longitudinal division in the radial plane, while, with others, including most of the deciduous fruit species, it is by nearly transverse division, the new cells elongating and crowding past each other.

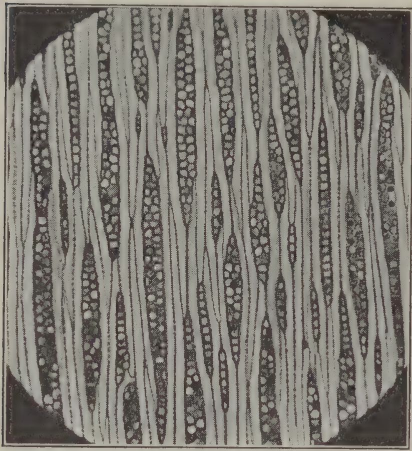

Figure 5. Tangential section through the cambium of the pear. (After MacDaniels.)

All the newly formed cells or cells in the process of division, of course, expand in some direction. And, during the growing season, there are cells in varying degrees of expansion and differentiation. Dr. J. P. Bennett, of the University of California, in some unpublished work, found, with young pear and apricot trees, that the nature of a season's growth rate for trunk circumference is similar to that shown in Figure 2 for shoot elongation. That is, the rate of circumference increase is slow during the early part of the season of growth, is gradually more rapid, and then gradually slower. The relatively slow initial rate of diameter increase would be expected even if cell division should be as rapid at the beginning as at any time later; for, at first, there would be fewer newly formed cells in the various stages of expansion.

The period of cambial growth may be rather short, particularly with older trees. A simple way of determining when cambial growth has not ceased, or has but recently ceased, is by the peeling of the bark. When there is, from recent cambial division, a thick layer of new tissue that is not fully developed, the bark peels readily. Trees are budded when strips of bark can be turned back. With young seedlings in the nursery, budding is generally done in August and may often be done in September. Cambial growth must, therefore, continue until that time or later. Nursery trees one or two years from the bud make rather large increase in thickness after September 1st, at least in the climate of Missouri. Some nurserymen have noted similar behavior in New York. Possibly this may result, not from new cambial division after that time, but from the completion of the growth of cells, from earlier cambial division. However, cambial division must have continued to very near that time. As with shoot growth, cambial growth is responsive to weather conditions. Thus, budders know that a few days of very hot, dry weather may stop their work for the season, due to the bark's becoming tight.

It would be well if we knew in what part of the tree cambial growth continues latest. It is known from experience with winter killing that wood and bark toward the bases of the trunks of trees (let us say ten years old or older) do not become resistant to freezing as early in winter as wood farther out on the branches. Whether this is due to later cambial growth, or to slower ripening of the tissue after it is formed, has not been determined; but observation of the splitting of the bark due to growth suggests that new tissue formation continues later at the bases. In microscopic studies, Knudson (206) found cambial growth ceasing rather early in summer at Ithaca, New York. The cambium was in the resting stage by July 19th, on a fifteen-year-old peach tree; by August 9th, on a thirty-year-old apple tree; before July 30th, on a Baldwin and a Rhode Island Greening apple tree about seventy-five years old; by July 17th, on a twenty-year-old pear tree, and by July 23d, on peach, plum, and cherry trees twenty years old. With the apple and the grape cambial activity did not begin until the leaves were of considerable size. With the peach, however, it began at the time of opening of the buds.

MacDougal (224), using the dendrograph and dendrometer, found with the beech at Baltimore, Maryland, that enlargement of the trunk did not begin until May 18th, during a spring when the leaves began to unfold April 10th. He found, with trees generally, except very young ones, that enlargement of the trunk continues only during two or three months even in a climate very favorable for growth. Enlargement must continue for a short time after cambial division has ceased; or until the new cells have reached full size.

Whether eventually the cambium goes into a rest period from which it does not respond to favorable growing weather, we cannot say from any carefully described experience, but rather general observations indicate that it does reach such a condition. At least with trees five or six years old, or older, a second cambial growth, great enough to cause the bark to peel after it has been tight for some days, seems very unusual even if heavy rains follow. Sometimes during dry periods the bark of young peach trees in the nursery may cease to peel easily, and may peel again very easily if a good rain follows. It is not certain, however, that in such brief dry periods cambial growth has entirely ceased or that the tissue has gone fully into the resting condition. Proebsting (278) found that cambial growth would not proceed unless leaves were permitted to grow. If the leaves were kept pinched away from a branch or from a whole tree, cambial growth ceased even though the supply of organic and inorganic nutrients seemed to be abundant.

Organic nutrients of fruit trees and fruit plants. (*Photosynthesis.*) The student is, of course, acquainted with the fact that organic food is formed by the process of photosynthesis principally in the leaves, though to a small extent in other green tissue. The mineral nutrients are necessary for growth; but, excepting water, the materials of which the tree and fruit are most largely composed are from substances formed in the leaf; and combination of these organic substances with at least some of the mineral nutrients, to give the compounds in which the mineral nutrients are used by the plants, takes place most rapidly in the leaves. Thus, the synthesis of organic nitrogenous substances such as proteins seems to proceed much more rapidly in the leaves than in other tissue.

Blackman (48) suggests that the rate of photosynthesis for a given leaf may be limited by the amount of carbon dioxide available, the amount of water available, the intensity of available radiant energy, the amount of chlorophyll present, and the temperature of the chloroplast. There seems to be an internal factor besides chlorophyll content that influences the response to variations in other factors such as light intensity (Willstätter and Stoll, 362; Spoehr, 319), but these limiting factors of Blackman are none the less important. Matthaei (236) found that, with leaves having optimal internal conditions and with other limiting factors optimal, there was with *Prunus laurocerasus* a rapid increase in assimilation with rising temperature from −5° C. to 37.5° C., but that when held at temperatures above 25° C. the rate fell rapidly, the fall being more rapid for the higher temperatures. It seems that sustained high temperature must have been injurious through its influence on some internal factor such as an enzyme. Mr. J. J. Grim, in some unpublished work at Cornell University, seemed to find, with leaves of privet (*Ligustrum ovalifolium*), that the rate of photosynthesis decreased during parts of the hottest days at Ithaca, New York. His conditions were such that the heat may, by increasing transpiration and thus reducing the water supply to the leaves, have caused the stomata to close. The rate was also reduced during very cloudy weather. It did not seem to be reduced by light cloudiness. In other words, the most direct and intense sunlight does not seem to be necessary for the most rapid photosynthesis. This is in agreement with the work of Young

(366), who found as much starch in the leaves of citrus trees when thickly covered with cement dust as in leaves not so covered.

The amount of carbon dioxide in the atmosphere seems under many conditions to be a limiting factor as to photosynthesis and as to growth. Brown and Escombe (54) found more carbon dioxide assimilated by detached leaves when more than the normal percentage of that substance was contained in the air passing over the leaf. However, with living plants enclosed in large inverted glass beakers, adding to the air passing through the beaker enough carbon dioxide, formed by reaction of weak hydrochloric acid with marble, to bring the amount in the air up to 5.4 parts to 10,000, did not increase growth and tended to injure the plant; though the air receiving additional carbon dioxide was passed through a sodium carbonate solution to remove possible injurious substances. A number of workers, including Cummings and Jones (90), Fischer (130), Riedel (290), and others, have seemed to find an increase in growth of some crops caused by supplying additional quantities of carbon dioxide to the atmosphere surrounding the plants. Cummings and Jones found that closed covers for the experimental plants were injurious; and so they used wood and glass frames open at the top. Into the center of these frames they conducted a slow stream of carbon dioxide generated from sodium bicarbonate and dilute sulphuric acid. They seemed to find with beans, potatoes, Swiss chard, cyclamens, and strawberry plants a considerable increase in growth to result; while with radishes and lettuce the differences were less conclusive. With the strawberry both foliage and fruit were larger and more abundant. Tissue of treated plants generally contained the higher percentage of carbohydrates. Riedel (290) seemed to find that if the soil was fertile the growth of plants could be increased by adding to the air the gas from high furnace chimneys. The benefit was noted when this gas was conducted into greenhouses or was permitted to escape into fields from perforated pipes near the surface of the soil.

The grower can generally influence the amount of photosynthesis only by influencing the extent of healthy leaf surface. The great expense of spraying is incurred in part for the purpose of avoiding injury to the foliage. Pruning, cutting away buds that would open into leaves, may reduce the leaf surface and therefore the possible amount of photosynthesis. Conditions that promote growth, such as a favorable temperature and abundant water and mineral nutrient supply, increase the leaf surface and the possible amount of assimilation. In other words, photosynthesis is important in determining the possible amount of growth, and growth through the formation of new leaves is important in determining the possible amount of photosynthesis. The amount of dry matter formed by trees of a given variety should, therefore, be rather closely in proportion to the amount of leaf surface borne during the lives of the trees. In Table 7 is shown the average amounts of dry matter in proportion to the amounts of leaf surface that had been borne by trees of several different kinds grown in the Cornell University orchard at Ithaca, New York, latitude 42.3°.

In the climate of New York one hundred square feet of leaf surface would generally be borne during the second summer in the orchard by an average, lightly pruned peach tree in good soil; in the third summer, by an average Montmorency or Early Richmond cherry tree; and in the fourth summer, by an exceptionally large apple tree that had been pruned little.

With the Elberta peach trees the leaves for dry weight determinations were taken from the trees concerned in Table 7. With the other kinds determinations were made for leaves of the same varieties in the autumn of 1923. However, with Elberta peach leaves dry matter determinations made in 1923 showed 1.55 pounds of dry matter to 100 square feet of area; exact agreement with the leaves from fertilized trees in Table 7. Of course, in all dry weight determinations for wood and roots, material was taken from trees in the experiment when they were dug up and weighed. Analyses published by Butler, Smith, and Curry (57) and by others indicate that 1.25 per cent to 4 per cent of the dry matter in the tops and from 1.0 per cent to 4.5 per cent of that in the roots is mineral substance that came from the soil, the remainder being organic material elaborated in the leaves. The fruit buds on the Early Richmond cherry trees were nearly all killed in winter and the other trees were not old enough to form fruit buds. As to whether the dry matter residue from the activity of a given leaf area would be greater or smaller with a fruiting tree, I know of no evidence.

Not nearly all the material formed in the leaves remains permanently in the tree structure or in the fruit. Much is consumed in respiration; though we have no very accurate means of estimating what percentage of the material formed is used in that way. When the sun is shining, the carbon dioxide that would be given off from the leaves as a result of respiration is generally all used in photosynthesis; and the oxygen given off from the leaves is not the total amount released in photosynthesis. It is the total less the amount used in respiration.

Generally with the trees of Table 7 for any one variety the residue of dry matter for a given leaf area is rather near to being uniform. With Early Richmond cherry trees (groups 1 and 2) severe pruning reduced the

TABLE 7. POUNDS OF DRY MATTER IN THE LEAVES, THE ROOTS, AND THE TOPS OF TREES TO ONE HUNDRED SQUARE FEET OF LEAF SURFACE BORNE

GROUP	TREES STUDIED	LEAVES	TOP (WOOD)	ROOTS	TOP (WOOD) AND ROOTS
1	Average for 12 Early Richmond cherry trees, unpruned, but fertilized with sodium nitrate. Grown during the seasons of 1917 to 1921 inclusive	2.18	5.06	1.64	6.70
2	Average for 12 Early Richmond cherry trees, pruned severely and fertilized. Grown during the seasons of 1917 to 1921 inclusive (dry matter of prunings included)	2.18	4.99	1.21	6.20
3	Average for 13 Montmorency cherry trees, unpruned and unfertilized. Grown during the seasons 1919 to 1921 inclusive (in a light gravelly soil)	2.19	3.93	2.05	5.98
4	Average for 24 Montmorency cherry trees, unpruned, but fertilized with sodium nitrate. Grown during the seasons 1919 to 1921 inclusive (in a light gravelly soil, slightly more retentive)	2.19	4.57	1.76	6.33
5	Average for 13 Montmorency cherry trees, unpruned and unfertilized. Grown during the seasons 1919 to 1921 inclusive (in a more retentive soil)	2.19	4.36	2.46	6.82
6	Average for 10 Elberta peach trees, unpruned and unfertilized. Grown during the seasons 1918 to 1919 inclusive (in a light gravelly soil)	1.60	2.11	0.91	3.02
7	Average for 30 Elberta peach trees, unpruned, but fertilized with sodium nitrate. Grown during the seasons 1918 to 1919 inclusive (in a light gravelly soil)	1.55	2.12	0.66	2.78
8	Average for 15 Henry Clay apple trees, unpruned and unfertilized. Grown during the seasons 1920 to 1921 inclusive (in a light gravelly soil)		5.34	2.80	8.14
9	Average for 24 Henry Clay apple trees, unpruned, but fertilized with sodium nitrate. Grown during the seasons 1920 to 1921 inclusive (in a light gravelly soil, slightly more retentive)		5.29	3.13	8.42
10	Average for 15 Henry Clay apple trees, unpruned and unfertilized. Grown during the seasons 1920 to 1921 inclusive (in a more retentive soil)		5.62	3.27	8.89
11	Average for 2 Wealthy apple trees, unpruned, but fertilized with sodium nitrate. Grown during the seasons 1920 to 1922 inclusive (in a well-aerated, retentive soil)	2.57	8.97	4.46	13.43
12	Healthy McIntosh apple tree, unpruned, but fertilized with sodium nitrate. Grown during the seasons 1920 to 1922 inclusive (in a well-aerated, retentive soil)	2.14	6.05	2.52	8.57
13	McIntosh apple tree, unpruned and fertilized with sodium nitrate, but having a weakening stock. Grown during the seasons 1920 to 1922 inclusive (in a well aerated, retentive soil)	2.14	4.18	3.53	7.71

residue of dry matter from a given leaf area; the probable error was small (782). It is not possible to determine how this reduction was brought about. The shoots grew later, and the average leaf, being formed later, may have been active during fewer hours of daylight. On the other hand, the tops of the unpruned trees were the larger and probably had the larger percentage of leaves in too much shade for most active photosynthesis. Since the pruned trees grew the later, probably a larger percentage of the dry matter of the trees was in the form of cell protoplasm following cell division and a smaller percentage in the form of storage material and additional thickening of the cell walls. And it may be that more material is required for respiration to furnish the energy for cell division than is required for the mere deposition of cellulose or storage materials.

With the Elberta peach trees (groups 6 and 7) there was a larger residue of dry matter from a given leaf area with unfertilized trees than with trees fertilized with sodium nitrate. The latter grew a little later in summer and became considerably larger, but did not hold their leaves later. The difference may, therefore, be due to the shorter average life of the leaves; to the greater amount of shade in the larger trees; to a greater amount of respiration, possibly stimulated by a larger amino nitrogen supply (Spoehr, 319); or to more than one of these influences. The additional amount of dry matter in proportion to leaf surface in the unfertilized trees was all in the roots.

With the Montmorency cherry trees (groups 3, 4, and 5) the smallest residue of dry matter to a given leaf area was for the unfertilized trees in the light gravelly soil. This, it seems certain, was due to the fact that these trees made a very weak growth and the leaves fell long before the end of the growing season. The largest residue was left by the unfertilized trees in the more retentive soil. These ceased shoot growth earlier than the trees fertilized with sodium nitrate, but the leaves, though of a lighter green, remained healthy until the end of the season; the additional amount of dry matter to a given leaf surface was all in the roots.

The Henry Clay apple trees (groups 8, 9, and 10) did not seem to respond in the least to the nitrate, but the trees were heavier and the dry matter from a given leaf area was greater in the more retentive soil with the better water supply.

With groups 11, 12, and 13, since so few trees were involved and those during but three years, the results may not be dependable. A rather small error in estimating the leaf area in one year would have an appreciable influence on the final result. If there were more trees or more years, the influence of such a single error would be reduced.

It may be that, with the very thick leaves of the Wealthy apple, photosynthesis is more rapid than with thinner leaves. It is interesting to note that the peach tree leaves have the smallest amount of dry matter to a given area and produce the smallest dry matter residue in the tree to a given leaf area. However, the young peach trees tend to grow later than do apple or cherry trees. The average life of a leaf is, therefore, shorter. Further, it may be that, with trees that continue growth so late, a relatively larger amount of dry matter is used for respiration. The number of stomata to a given leaf area was not estimated; and so it is not possible to say how differences in this regard may have influenced the results.

Some of the organic substances. The organic substances found most extensively in the plant and composing most of its dry matter are carbohydrates: sugars, starches, gums, and cellulose. The sugars most widely found in plants are glucose or dextrose, levulose or fructose, and sucrose or saccharose. Some of the sugars, such as the pentoses, are found in rather small quantities, except as groups in more complex molecules, such as the gums, like pentosans. The pentose group is said to be found in the nucleic acids of the cell nucleus (Spoehr, 318, p. 75). Sugars are in solution in the cell sap and some are always present at least in small quantities. Sugars can readily be transported in the plant and may be used in synthesizing starch or other material for storage. Starch is, with most fruit trees, by far the most important reserve material, and the quantity of starch in the tissue varies much more than does the quantity of sugar. It is deposited when growth is not rapid enough to use nearly all the organic food for respiration and to form new cell structure. When growth, for any reason, becomes very rapid, as with that in spring and early summer, the supply of starch that has accumulated may be rapidly depleted.

Other important organic materials are the fats and the lipins. These seem to be constituents of the protoplasm, but they may also accumulate in considerable quantities as reserve food.

Much of the organic material in the plant is in combination with nitrogen. Proteins, which contain also sulphur and some of which contain also phosphorus and iron in the molecules, are constituents of protoplasm and may be in solution in the sap and in solid form, often in large quantities, as reserves. The organic nitrogen compounds that seem to be most active in growth are amino acids and amides. Spoehr (319) seemed to find the rate of respiration increased by increases in the amount of amino acids and that conditions favoring high respiration tended to cause an increase in the amount of these substances. Since respiration releases the energy necessary for growth it seems probable that amino acid smay be very important as influencing the rate of growth.

Kraus and Kraybill (211) have emphasized the importance of the carbohydrate-nitrogen relationship, among other features, determining growth and fruitfulness; an abundant, though not excessive, supply of nitrogen relative to carbohydrates encouraging growth. With these authors and later in Kraus's laboratory the importance of various nitrogenous compounds has had attention. It may be that the kind of nitrogen compounds rather than the total amount of nitrogen in the tissue is the important influence as to growth. Further, we have seen that not all the organic non-nitrogenous material is carbohydrate; though perhaps, because of their preponderance, the amount of carbohydrates may be a fair measure of the total supply of organic material available for growth and respiration. If the water supply, the temperature, and other environmental features were optimal, it might possibly be expected that the nitrogenous compounds present in the tissue would be those most favorable for growth, and that a determination of total nitrogen would dependably indicate the amount of active nitrogen. However, either early or late in the growing season, growth is nearly always checked due to environmental causes such as lack of water; and it seems probable that, with the resulting accumulation of carbohydrates, there might be a tendency for a larger percentage of the nitrogen to be in the form of insoluble proteins not immediately active in promoting growth. I know of no convincing evidence that the mere accumulation of carbohydrates inhibits growth, though it might cause the nitrogen to be combined in larger organic molecules and possibly in forms less active in immediate promotion of growth. In other words, if growth is checked by lack of nitrogen, it does not seem certain whether or not the accumulation of carbohydrates, particularly of insoluble forms such as starch, will check it farther. Shading the plants (Kraybill, 212, and others) or removing some of the leaves (Harvey, 158, and others) may promote or prolong the vegetative condition, and either treatment reduces the carbohydrate supply by reducing photosynthesis; but these treatments probably influence the plant in other ways than merely by reducing the carbohydrate supply. Shading seems to cause a larger part of the nitrogen to be in the form of amino nitrogen, and both treatments by reducing transpiration may increase the water supply to the growing points. Since the reserves are much more largely of carbohydrates than of nitrogenous compounds, and since with rapid growth there is less reserve, it is to be expected that the carbohydrate-nitrogen ratio will tend to be more narrow the more rapid the growth. However, it does not seem improbable that, with nitrogen the most important limiting factor for one tree and water supply for another, the rate of growth might be the same, but the carbohydrate-nitrogen ratio much greater in the tissue of the former than in that of the latter.

Tissue in which organic substances are transported. It is well known that, with plants such as trees that do not have internal phloem, when a ring of bark is cut away the downward movement of substances elaborated in the leaves is checked. If live cambium is left and new bark is formed, the check will be only temporary; but, if the cambium is scraped off or if it dries out from being exposed to the air and no new bark is formed, downward movement of such material is stopped and the part below the ring eventually dies from lack of organic food. This behavior has generally been accepted as proof that material elaborated in the leaves moves downward through the phloem. Dixon (103), however, calls attention to the fact that when a ring of bark is removed, there is a tendency for the xylem vessels to be partly plugged with gum. Daniel (96), Combes (73 and 74), Higgins (830), Gardner (810), and others have found evidence of such gum formation.

Masses of gum in the vessels might possibly behave as semipermeable membranes and thus prevent or inhibit the passage of material dissolved in the water of the vessels. Dixon thinks that in uninjured plants the downward movement of material from the leaves may be in the xylem (sapwood). However, Professor O. F. Curtis, in some unpublished work, found that, when he split the root systems of small trees and removed a section of the sapwood from one half and a section of the bark from the other, the roots died, apparently from lack of food, below the section with the bark removed, and those remained alive on the other half below the section with the wood removed, but the bark left. This suggests that the food must have moved downward only through the bark.

Atkins (25, pp. 186–219) and Dixon and Atkins (104) found rather large quantities of sugar in the xylem; and they and many others think that the upward movement of these substances is in that tissue. However Curtis (93), seemed to find that sugars cannot move rapidly in the xylem. When the leaves were stripped from a shoot and a ring of bark was removed, no sugars would move past the top of the ringed part. Growth might be resumed when food was made available by new leaves that had formed, due to the small amount of carbohydrates there when the ringing was done. With fruit trees when the leaves were removed from a spur, or small branch containing one or more fruits, and a ring of bark was removed, the fruit would not grow; while if the leaves were removed, and the ringing was not done, the fruit would grow. Evidently the ringing had prevented the carbohydrates from moving outward to nourish the fruit. In this case, also, there is the possibility that plugging of the xylem with gum, rather than the disconnection of the phloem, prevented the passage of the sugar.

If organic material moves downward and upward through the phloem, it seems probable that organic nitrogen compounds may also. It has generally been assumed that mineral nutrients not in organic combination move with the transpiration stream in the xylem. But Curtis (95) found that ringing greatly reduced the amount of nitrogen and apparently the amount of other nutrients to pass into the branch. With nearly all of his ringed branches, Curtis covered the ringed area with paraffin at once after scraping the cambium. In some laboratory studies with pieces of branch containing a ringed section that had not been covered with paraffin, water could not readily be forced through, although it was easily forced through an unringed branch. This suggests that the conducting tissue was rather badly plugged, and that, although water enough may have passed the ring to keep the tissue above it in a reasonably healthy condition, material in solution could have been prevented from passing. However, in some later unpublished work, Curtis found that, with tissue covered with hot paraffin as soon as the bark was removed, there was, at least in many cases, no tyloses that could be detected microscopically and water could be forced through such ringed section very readily. And in these same cases ringing inhibited the passage of nitrogen and carbohydrates. It does not seem, therefore, that the formation of tyloses invalidates much if any of Curtis's work.

Gardner (810) studied the effect of ringing on the plugging of the xylem of the pear. He found that in ringing with a knife apparently about twenty-five per cent of the cross-section of the xylem of the ringed part was injured, either mechanically by the knife or by being plugged with gum. However, when he ringed by removing the outer bark and killing the other with potassium hydroxide, he could, by means of repeated treatments, keep the new phloem killed with no apparent injury to the xylem either directly or by plugging; yet the movement of carbohydrates past such a ring seemed to be prevented and the shoots seemed to behave as when ringed with a knife. These observations suggest that, at least with the pear, plugging of the xylem under the ring could hardly account for the failure of material to pass such a ring.

It seems to me that, although the evidence may not be conclusive, it at least suggests rather strongly that the movement of organic nutrients upward and downward and of mineral nutrients upward is largely through the phloem. Whether this is true or not, it is certain that removing a ring of bark from plants not having internal phloem will reduce the movement of both organic and inorganic material into the part above the ring. Ringing may, therefore, be used as a means of reducing the amount of nitrogen moving into the part above the ring; and, if leaves are left above the ring, as a means of increasing the concentration of carbohydrates there.

If the leaves above the ring are removed, both photosynthesis and the movement of carbohydrates into that part being prevented, the concentration will be lowered. There is some movement of nitrogen upward through the ringed part; probably little or no movement of organic nitrogen backward through that part; and a considerable amount of nitrogen will have gone into the branch before the ringing. Even if there is no growth, organic material will be used in respiration. The carbohydrate supply will, therefore, generally be lowered more than will the nitrogen supply. In fact, since increase in cellulose and other carbohydrates is stopped, the percentage of nitrogen in such shoots may remain higher than that in shoots containing leaves.

Both Curtis (93) and Harvey (158) found that ringing, even though the leaves are left on the ringed part, reduces growth in that part, if the ringing is done early in the season; but they seemed to find that, if the ringing is done later in the season, it may increase the amount of growth above the ring; perhaps retaining carbohydrate or organic nitrogen compounds above the ring may have increased growth. The differences were rather small, however, and may not have been significant. Both these workers found that ringing and defoliating the part above the ring stopped length growth very quickly. Curtis found the osmotic concentration lower in the shoots that were ringed and defoliated than in untreated shoots. Shoots with a reduced osmotic concentration seem to be at a disadvantage in the competition for water. Curtis thinks that the checking of growth may have been due in part to a reduced water supply. Harvey found the percentage of water in the ringed defoliated shoots considerably higher than that in other shoots. Such a condition would be expected, since, with less starch in the cells and perhaps less cellulose in some of the tissues, there would be more room for water. Early in the growing season the water content of shoots is nearly always greater than that later in the season; there being less starch, gum, and woody material. The ringing with defoliation tends to stop the development of the shoot in that early stage. A high water content in such shoots is, therefore, not necessarily proof that the water supply throughout the day is sufficient to keep the cells turgid and to support growth. To obtain information as to the adequacy of the water supply, it would be necessary, by means of determinations throughout the day, to learn how much the water content declines as transpiration increases during the day. (See Chapter 8.)

Harvey found more nitrogen relative to carbohydrates in the ringed defoliated shoots than in others, and he thinks that fact may explain the sudden checking of growth. In fact, he suggests that all the differences in growth caused by ringing and defoliation may possibly be explained by the differences he found in the carbohydrate-nitrogen ratio. However, he explains that the problem is complicated, and that ringing as well as defoliating may influence growth in other ways than by changing the carbohydrate-nitrogen ratio. It seems to me that we cannot know of what importance rather small changes in that ratio may be in explaining the influence on growth caused by such extreme treatments as ringing and defoliating until we have more information as to what differences in that ratio there may be found among shoots making equally rapid growth.

When only shoots or very small branches are defoliated or ringed, and leaves are left on the part below, there will generally be a reduction (though sometimes not an appreciable reduction) in the carbohydrate supply below, and a lowering of the carbohydrate-nitrogen ratio. And if all of a branch is defoliated, or if it is ringed so low that little or no leaf surface is left below the ring, there will be such a reduction in the carbohydrate supply below that growth in thickness will be greatly reduced; though, with ringing, buds just below the ring may be caused to grow.

With such ringing or defoliation of large branches, probably specific sections of the root system rather than the entire system will have growth reduced. Thus, Auchter (30) seemed to find that, when he defoliated one side of a tree, the organic nutrient supply to the roots under the defoliated branches soon became less than that of roots under the non-defoliated branches. He and Knowlton (649) have published evidence indicating that nitrogen and, perhaps, other mineral nutrients tend to move from certain roots to certain branches. When soil on one side only of a tree was fertilized with nitrogen, there was a greater shoot growth and a higher nitrogen concentration in the branches on that side.

Accumulation of organic substances at different seasons. Generally much the largest part of the reserve food supply of the tree is starch, though Tottingham, Roberts, and Lepkovsky (330) seemed to find that the acid-hydrolyzable material, commonly known as "hemicellulose," may be of considerable importance as a reserve carbohydrate supply in apple wood; the alcohol-soluble fraction resulting from hydrolysis contains a large amount of the sugars, xylose, and glucose and a small amount of galactose. A considerable number of workers have studied the seasonal distribution of starch and other materials in trees, and a few of these studies that seem most closely to relate to orchard problems will be discussed here. Fischer (129) found the parenchyma cells filled with starch in October. At that time, however, starch began to disappear; fats and glucose taking its place. In some trees, this transformation took place in the bark only, starch remaining in the woody tissues. Tuttle (339), working at Edmonton, Canada, studied many species of woody plants as to starch and other reserve carbohydrate content, and found with all species that starch, which was present in large quantities during the summer, disappeared in October. All but a few of the species examined contained fats and oils as reserve material during winter; and some contained both starch and oil during the vegetative season. No very important fruit species was studied.

Price (277) in studying the storage of starch in an old apple tree in Ohio, latitude 41°, found that during the dormant period starch is stored in the living cells of the pith, wood parenchyma, and medullary rays of the apple tree. With the approach of spring, it is found in the tissues of the bark. As the leaves begin to appear, starch begins to disappear from the tissues in the following order: bark, wood-parenchyma, medullary rays, pith. It disappears first from the youngest wood of the upper branches, later from the lower parts of the tree, and finally from the roots. Sometimes a part of the starch remains unused and is included in the heartwood. During the year his studies were made, bud swelling was apparent on March 9th. The leaves were unfolding by April 24th, and starch had then largely disappeared from the bark of parts one to eight years old, the wood-parenchyma of wood one to three years old, and the medullary rays of wood one year old. By May 12th starch had nearly disappeared from all living tissue above ground. Hooker (181) also found almost complete disappearance of starch from the fruit spur of the apple soon after growth had started.

Mitra (239) studied, for apple spurs and young apple seedlings, the seasonal changes in the content of starch and sugars. With the spurs, and with the seedling tissue above ground, starch was low soon after growth started, the amount increasing markedly through August and into September, the maximum being reached in September for the spurs and in October for the wood of the seedlings. With the beginning of cold weather, the amount of starch began to decrease, the decrease continuing until February. During that time the percentage of total sugars increased, but not enough to account for the decrease in starch. Some of the starch was changed to sugars, and Mitra thinks some may have been changed to fat. (During the time, there was, of course, some carbohydrates used for respiration.) In the roots of the seedlings the increase in starch after growth ceased was greater than in the top, and the maximum was not reached until December, after which there was a rapid decline. As with the twigs and spurs, only a part of that decline could have been due to the formation of sugar. In fact, the percentage of total carbohydrates decreased rather markedly at this time. During January and February there was in the roots a latex-like material which he thinks may have been fat. This disappeared in February when there was a small increase in total carbohydrates.

Mitra found sucrose in the tissue only in rather small quantities. He thought he found considerable quantities of maltose in the twigs and spurs. Late in the summer, during the period of accumulation and translocation of carbohydrates, the amount of maltose seemed to be considerably greater than the amount of glucose. In late winter and spring the amount of glucose was generally much larger than the amount of maltose. Harvey (159) says that in Mitra's analyses for maltose, after treatment for inversion, the material was hydrolyzed with two per cent hydrochloric acid for three hours, and that such a treatment would hydrolyze the glucoside phloridzin yielding glucose, which would be measured as reducing sugar as would the product of hydrolysis of maltose. In other words, by such hydrolysis alone one cannot be certain whether one is determining the amount of maltose or the amount of phloridzin. Fortunately, however, while upon hydrolysis maltose yields only reducing sugars, phloridzin yields glucose and phloretin. The amount of phloridzin can therefore be determined either by hydrolysis and analysis for glucose (reducing sugar) or by hydrolysis and analyses for phloretin. And Harvey obtained approximately the same percentage for phloridzin when he analyzed the acid hydrolyzed apple tissue for reducing sugar as when he analyzed for phloretin. He, therefore, thinks it probable that it is phloridzin instead of maltose that Mitra found in rather large quantities in apple tissue. In another study, Harvey (158) generally found considerably more phloridzin than sucrose and reducing sugars (total sugar) in apple shoots in Oregon during the months of June, July, and August.

Butler, Smith, and Curry (57) analyzed a considerable number of apple trees grown in the climate of New Hampshire (latitude 43°). Their analyses were with trees taken while dormant (December 3d), when the buds were swelling (April 20th), when in bloom (May 18th), after shoot growth had ceased (July 12th), and when the leaves were falling (October 12th). In all parts of the tree they found the percentage of starch lowest when the trees were in bloom, and next lowest during mid-winter. With most of the tissues it was highest when the buds were swelling. There was little difference in the percentages in mid-summer and in autumn. Unfortunately, no analyses were made during the early part of the period of rapid growth shortly following the bloom. From the results of other workers, it is probable that the starch content would have been found lower than at blooming time. With their method of analysis by hydrolyzing with weak acid, they would probably have found no time when there was not a considerable amount of starch indicated to be in the tissue; for by such hydrolysis there was probably included as starch much that was not starch, probably some cellulose and certainly other substances from the cell walls. These workers found considerable quantities of fat in the tissue at all times; more in the young shoots and the young roots than elsewhere. If fat is a constituent of protoplasm, this is to be expected; for there is less non-living conducting tissue, and therefore perhaps relatively more protoplasm, in such young tissue. They found sugars present in rather small quantities and no conspicuous differences in the different seasons of the year; except that, in early spring and late autumn, sucrose, and, at blooming time, reducing sugar, were present in considerably larger percentages in the small roots than in other tissues.

The workers quoted so far were in sections where there is continuous or nearly continuous freezing weather during December, January, and February. Cameron (58) studied the storage of starch in apricot and pear trees at Davis, California, where there is little freezing weather. As would be expected, he found the amount of starch becoming gradually less from the beginning of spring growth until it reached a minimum during May and early June, when growth was rapid. Starch disappeared first from the terminal part of the growing shoot and later progressively downward. He found the starch content high in October and early November, declining until January and early February and rising to another maximum in late February. In other words, the low starch content is found in mid-winter, not only in sections where there is much freezing weather, but also in sections where the winters are mild.

Mr. B. Hahne, in some unpublished work, found similar results with young pear trees at Berkeley, California, though the reduction in starch content in mid-winter was hardly as great as that in mid-winter in colder climates. In winter he seemed to find the fat content increasing when the starch content decreased. In early summer the fat content declined for tissue above ground as did the content of other storage materials; but in the cortex and phloem of the roots the amount of fat and protein seemed to rise in May when the starch content was low.

Butler, Smith, and Curry suggest that, since in spring the content of sugar is much higher in the small roots than elsewhere in the tree, the upper part of the tree must be supplied with carbohydrates for early spring growth from these small roots. A high percentage of sugar in small roots or toward the end of twigs does not necessarily mean that the concentration in the sap is high. It may mean only that the amount of storage tissue is large in proportion to the amount of non-storage or of non-living tissue. The percentage of dead tissue, such as heartwood and non-living elements of the sapwood, is larger in the older parts of the tree, the large branches, the trunk, and the large roots. The roots are generally found very rich in storage material and the small ones particularly so; but because of their small bulk the total amount of starch or other material in the small roots or in the twigs is small compared with the amount in the remainder of the tree. In Table 8 is shown the dry weights of the different parts of a Bismarck apple tree seven years old, and estimates as to the amount of starch and sucrose, using the percentages given by Butler, Smith, and Curry.

TABLE 8. ESTIMATED AMOUNTS OF SOME CARBOHYDRATES IN DIFFERENT PARTS OF A TREE

PART OF TREE	POUNDS DRY WEIGHT	POUNDS STARCH	POUNDS SUCROSE
1 year twigs	3.15	0.98	.12
Older branches	21.00	6.72	.17
Trunk	15.13	5.14	.11
Large roots	14.15	5.43	.28
Small roots	6.49	2.37	.06

The figures for starch are probably much too high because of the acid hydrolysis method used by those workers; but the error would be found in all the tissue. The total amounts of starch or of sucrose in the twigs is very small compared with that in the remainder of the tree. Yet from these a much greater amount of growth is made, relative to their size, than from older parts. It is not surprising that in spring the reserves are rather quickly exhausted from the twigs; and it seems probable that, if they are not so quickly exhausted from the roots, it is because temperature, the oxygen supply, or some other environmental feature is not favorable for growth. Even though the percentages may be lower, the greater part of the reserve material is in the large roots, the trunk and the large branches.

Sap concentration at different seasons. Not all the organic or inorganic constituents, soluble or insoluble, are known. The results discussed in this chapter suggest that the amount of sugar is not large. Yet the total osmotic concentration of the sap is considerable; and much more of it seems to be due to organic material than can be accounted for by sugar analyses (62). The total osmotic concentration can be estimated roughly by means of boiling-point, freezing-point, or vapor-pressure determinations of expressed sap; the most feasible generally being the freezing-point determination. With any substance that is not volatile and does not dissociate or associate in solution, the molecular weight in grams dissolved in a litre of water lowers the freezing point about 1.86° C. With some organic substances such as sugars there is no dissociation; and so if, with a solution of such substances, the freezing point should be −3.72° C., the concentration would be about twice the molecular weight in grams in a litre of water. With inorganic substances and to some extent with organic acids, which in solution are partly dissociated, the dissociated ions lowering the freezing point as molecules, considerably less than the molecular weight in grams in a litre of water will lower the freezing point 1.86° C. Inorganic substances in solution conduct the electric current while most organic substances do not, and others, such as the organic acids, do so relatively feebly. It is, therefore, possible by means of freezing-point studies to determine the total osmotic concentration of organic and inorganic substances, and by means of electrical resistance studies (62) to estimate the concentration of mainly inorganic substances; the difference indicating very *roughly* the molecular concentration of organic material (the difference being due, in fact, to the non-dissociating organic molecules, such as sugars and to the incompleteness of dissociation of other organic molecules, such as organic acids, and organic nitrogenous compounds). Such studies suggest that much the larger part of the material dissolved in the sap of the bark is organic, and that the amount of organic material in solution may be considerably greater than the amount of sugar as indicated by analyses. It seems that some of this material may be available in the plant either for the building of tissue or as a source of energy through respiration. Further, many of the mineral ions in solution are associated with complicated organic groups that are capable of being used either for tissue-building or for energy. Most of the nitrogenous material is of this kind. It seems, therefore, that a measure of the osmotic concentration in a tissue may indicate roughly the amount of energy-supplying material in solution. It, of course, gives no indication as to the amount of such insoluble substances as starch, some of the proteins, and fats. Further, it can be only a rough indication as to the amount of available food in the soluble material. For 342 grams of cane sugar, or several thousand grams of soluble protein, would lower the freezing point no more than would 134 grams of malic acid. Yet there would be a very much greater food value in the 342 grams of cane sugar or the several thousand grams of protein.

Reed (288) found in California that the osmotic concentration of sap of apricot shoots, wood and bark being ground together, is much lower during rapid growth than after growth has become slow or has ceased; the concentration in late summer being far greater than that in May in California where growth starts in March or early in April. This increase in concentration is in approximate agreement with the findings as to accumulation of starch and other storage materials.

Similar results were obtained in Missouri (62) with sap from the bark of various parts of fruit trees, and at Ithaca, New York, with the bark of twigs and young branches of several kinds. Table 9 is for the year 1916 at Ithaca.

TABLE 9. SHOWING THE NUMBER OF DEGREES BELOW ZERO CENTIGRADE AT WHICH SAP, EXPRESSED FROM THE BARK AT DIFFERENT TIMES OF THE YEAR, FREEZES

DATE	ELBERTA PEACH		P. AVIUM		R. I. GREENING APPLE		BALDWIN APPLE	
	Depression	Moisture percentage	Depression	Moisture percentage	Depression	Moisture percentage	Depression	Moisture percentage
March 25	3.003		2.255		2.553		2.368	
May 3 (buds bursting)	1.880		1.485		1.705		1.637	
May 18	1.378		1.295		1.083		1.417	
June 1	1.540	59.2	1.120	60.1	0.983	65.7	1.068	61.5
June 9	1.810		0.985		1.035		1.055	
July 19	2.150		1.553		1.803		1.613	
August 17	2.230	62.0	1.730	61.4	1.335	65.7	1.448	63.1
October 5	2.567		1.763		1.608		1.633	
December 29	2.567	54.6	2.563	54.3	2.665	52.7	2.603	54.2

The least concentration was found about June 9th for the apple and the cherry, and a little earlier for the peach. Full bloom with most varieties of apples during that year came May 23d, with the sweet cherry May 15th, and with the peach May 22d. The peaches had little bloom, which fact may account for the more rapid rise in concentration. The branches for these records were always taken in early morning so they would be turgid. The apple trees were about fifty years old and made a rather good shoot growth in the top. Length growth ended, for most shoots about June 9th.

The osmotic concentration continues low during the period of growth, and rises as soon as the carbohydrates cease to be used for that purpose. On July 19th, with the apple, there was a high concentration. The weather then was very hot and there was much clear sunlight. Reduced sap concentration at time of most rapid growth and gradually increasing concentration afterward were found also during the seasons of 1915 and 1917, at Ithaca, New York, and during preceding seasons at Columbia, Missouri (62). It might be thought that the variation in concentration is due to variation in the amount of water in the tissue rather than in the amount of carbohydrates. The moisture percentage at several periods was, therefore, determined, and is shown in the right-hand column for each variety. The water percentage is not higher at the time of lowest concentration in June than at the time of the much higher concentration in August. It is lower in December, which fact may account in part for the greater concentration at that time. The period of low concentration of soluble organic substances like that of low starch content (Cameron, 58) is longer with young vigorously growing trees, or trees made vigorous by severe pruning than with older and less vigorous trees (62, and Reed, 288). There is some increase in concentration, however, as soon as there is a rather large leaf surface; the products of photosynthesis may accumulate even while a rather rapid growth is being made.

Generally, if the tissue from which sap is to be expressed is killed by freezing before it is ground, the osmotic concentration of the sap expressed will be higher; material that would be held by the protoplasm will be released. With leaves, the difference caused by such freezing is rather great. In the work done at Missouri and at Ithaca, the tissue was not killed. Facilities were not available for killing the resistant winter tissue. However, I have repeatedly made determinations with sap from summer tissue killed and not killed before grinding; and, while the concentration with sap from killed leaves was much greater, the concentration of sap from frozen bark seemed never to be greater than that from bark ground without freezing. The results with bark seem, therefore, to be dependable.

In Missouri, during most of the year (62, p. 510), osmotic concentrations were found to be lowest in the bark of roots, and to increase upward, being highest in the bark of shoots. The concentration in the leaves is much greater than in bark at any level. The one period when the concentration in the roots was not less than in tissue above was in May, when the carbohydrates were probably being used the more rapidly in the top, for opening leaves and flowers. At that time the concentration in root and trunk bark was as great as in the twigs and small branches, or greater. We have seen that removing a ring of bark prevents the movement of carbohydrates upward or downward past the ringed part. In summer the increased osmotic concentration above the ringed section and the decreased concentration below the ringed section are rather striking, provided there are few or no leaves below the ring. Thus (62, p. 520), an Elberta peach tree was ringed close to the ground on June 5, 1911. By August 3d, the freezing-point depression of the bark sap of the roots of the ringed tree was .650° C., as against 1.470° C. for the roots of a similar tree not ringed. The depression of bark sap from the trunk and main branches above the ring was 1.900° C., as against 1.430° C. for the tree not ringed. For the shoots it was, ringed, 2.020° C., not ringed, 1.760° C. It is interesting to note that with the tree that was not ringed there was a much wider difference between the trunk and shoot-bark sap concentration than with the ringed tree. This would be expected if in the ringed tree there was an excess of substances that could not move past the ring to be used for root growth below. Unfortunately, with this Elberta peach tree, no records were taken between June 5th and August 3d. With a Gano apple tree, ringed on September 10th, the root-sap depression had decreased and the shoot-sap depression had increased measurably by September 25th.

Removal of leaves from a tree, of course, stops the carbohydrate formation and the sap concentration should be lessened. In fact, it is lessened strikingly. Thus (62, p. 521) with both apple and peach trees two weeks after the leaves were removed the concentration was greatly lowered in the bark of roots, trunk, branches, and shoots. The falling of concentration was greater in the shoots, where the carbohydrates were originally most abundant. After the leaves were removed, the carbohydrates and other organic material might have continued to move downward approaching equilibrium at the different levels; and much would probably be used in the shoots for new leaf growth.

These experiences suggest that measuring the osmotic concentration of the sap of plants may give some information as to the total supply of soluble food in the tissue; but, even if that information should be found too general or unreliable, since osmotic concentration seems to vary inversely with the vegetative activity, records of that concentration may be found useful as indicating the vegetative condition of wood at a given time.

Summary. While a young tree may grow in length and thickness as long as the weather is warm enough for growth, older trees cease growth in both length and thickness rather early in summer; older trees pruned severely may grow as late as young ones. Growth of shoots aboveground is with the common deciduous fruit trees nearly always from buds. Even the sprouts on old wood are generally from buds. Sprouts may grow from the tissue around a bud or around the base of a shoot, but it seems probable that they are from dormant buds that grew in the axil of bud scales. The adventitious shoots from callous tissue, that are very common with the beech and the poplar, are seldom if ever found starting aboveground with these fruit trees.

Trees under the same weather and climatic conditions will make growth (when fruit is included as growth) at least approximately in proportion to the leaf area; and increased concentration of carbon dioxide in the atmosphere sometimes increases growth. When the supply of water and mineral nutrients is abundant, carbohydrates formed in the leaves are used for growth and there is very little accumulation. However, such rapid growth results in a very large leaf surface and consequently in a very great transpiration, which tends to check growth. With the large leaf surface there is increased photosynthesis. With a tree that makes very vigorous growth, therefore, accumulation of carbohydrates may begin only a little later than with one making rather weak growth. Organic nitrogenous materials also seem to be synthesized in the leaf. When the products of photosynthesis accumulate, there is an increased concentration of soluble carbohydrates and an increased storage of insoluble forms. Starch is generally the most abundant insoluble form, but there may be storage also, as fats, lipins, proteins, cellulose compounds and other substances. In sections where the winters are cold, and in a section, such as California, where there is little freezing weather, the starch content tends to decline about mid-winter; rising again in late winter or early spring before growth starts.

There is some evidence that soluble carbohydrates and nitrogen do not move rapidly upward or downward through the xylem, but move both upward and downward mainly through the phloem. At least, cutting away a ring of bark inhibits or prevents the passage of these substances; and both seem to pass upward from certain roots to certain branches and downward from certain branches to certain roots.

CHAPTER 2

FRUIT-BUD FORMATION

It is known to the student that with nearly all fruit trees the flower parts are formed in the buds during the summer before the flowers open. Before entering upon a discussion of fruit-bud formation, a brief review of the nature and position of fruit buds of our common orchard trees will be useful.

Nature and position of fruit buds of the different species. There are lateral or axillary fruit buds — that is, fruit buds borne in the axils of leaves — and terminal fruit buds — those borne on the terminal of a shoot or of a spur.

With the peach, nearly all buds are axillary on shoots, though some are axillary on very small shoots that by some are called spurs. These, like the buds on longer shoots, however, are subtended by a single leaf. Each bud opens into a single flower. With weak shoots generally only one bud forms at a node; but with large vigorous shoots there may be three buds at most of the nodes, the central one usually being a wood bud and the two outer ones fruit buds. There are three leaves at such a node, the central one being the largest.

With the apricot the fruit buds contain single flowers and are borne in much the same way as with the peach, except that, in California, at least, long shoots are likely to bear fruit buds only near the terminal; that is, in the last growth cycle of the season. However, there may be fruit buds on wood of earlier cycles, and they are found throughout the length of some shoots, and of spurs (short shoots) along young and old branches.

With the plum, also, fruit buds are borne axially on spurs and on longer shoots. Except with the Japanese plum, however, a smaller percentage of the buds on rather long shoots are fruit buds with the plum than with the peach. On strong shoots of the peach, the apricot, and the plum there may be, at some of the nodes, a leaf bud with a fruit bud on each side of it; or on one side; exceptionally, all three of these are fruit buds; in the summer, when the buds are being formed, there is a large middle leaf with a smaller one on each side; in other words, each bud is subtended by a leaf. A fruit bud of the plum opens into one to three, or sometimes more, blossoms. The terminal bud seems always to be a wood bud subtended by a single leaf. Therefore, in the succeeding year the twig, barring accident, always continues growth from the end.

With the cherry, also, the fruit buds are generally axillary on spurs or shoots; the terminal bud of the shoot, and generally of the spur, being a wood bud subtended by a single leaf. With an old weak spur the terminal bud seems to be subtended by a number of leaves. Such a bud may be a fruit bud, the spur dying after the fruit is borne. With the sweet cherry (Kraus, 207), where the shoots are of considerable length, the tendency is for fruit buds to form only on the basal half. With the sour cherry, shoots less than five or six inches long may bear only fruit buds except at the terminal. With longer shoots, some of the buds are wood buds, which may grow into spurs. A tree with a large spur system seems to fruit more dependably (Roberts, 890). A fruit bud of the cherry opens into a cluster of several flowers.

With the apple and the pear much the largest percentage of the fruit buds are borne terminally on spurs. These growths are short and the leaves are crowded into a compact whorl just back of the terminal. The buds in the axils of spur leaves are generally developed so slightly that they are not apparent. Often, the terminal bud of a shoot (sometimes of a shoot several feet long) is a fruit bud. Such a bud may be subtended by a single leaf, or two, or even three, may be so near it as to resemble the condition of the whorl of leaves on a spur; however, the spur may have three to eight or nine leaves closely around the base of the terminal bud. Where two or three leaves are closely around the terminal bud of a twig, the axillary buds are but slightly developed. It is not always easy to distinguish between a twig (a shoot from which the leaves have fallen) and a spur. They grade into each other. A typical twig is rather smooth, while the spur is rough, due to the closeness of the leaf scars. With many varieties, a spur must be two years old, or older, before it will form a fruit bud. With some varieties, such as Sheldon pear or Northern Spy apple, the spurs formed on young trees may be so small and weak that if they ever form fruit buds it is not before they are five or six years old, or older. Thus, spurs two or three years old in the top of Sheldon pear trees may bear fruit before those on the lower branches that are four or five years the older. It is fortunate, with young trees, at least, when spurs of a variety will not form fruit buds until they are two years old, for the fruit is not then borne so near the ends of the branches. Thus, with the McIntosh apple tree, fruit buds are seldom borne on the terminal of twigs, and the spurs generally do not form fruit buds until their second summer. Generally, therefore, with young McIntosh trees fruit is not borne within two to three feet of the ends of the branches; and, while this is one of the best early bearing varieties, the young trees maintain a good form. With some varieties like Wealthy, Wagener, and Rhode Island

Greening, with which the spurs form fruit buds during their first summer, the fruit is borne so near the end of the branches that they are bent to the ground. The earliest fruiting branches of such varieties are liable to become worthless while the tree is still rather young.

Many varieties of apples and pears may, during favorable summers, form fruit buds in axils of shoot leaves as with peaches, plums, and cherries. Varieties of apples, such as Wealthy, Wagener, Oldenburg, Jonathan, and Rhode Island Greening, and of pears, such as Bartlett and, particularly, Winter Nelis, very commonly form such buds in New York; and, in some years very favorable to fruit-bud formation, trees of nearly every variety of apples and of pears form at least a few such buds. Thus, at Ithaca, New York, McIntosh apple and Bosc pear are among the varieties least likely to form such buds, and yet they have been found on trees of both of these varieties during several of the past ten years. According to Kraus (207) many such buds are borne in Oregon on Ben Davis, Hyslop, Jonathan, Transcendent, Wealthy, and Winesap apple and Angouleme, Bartlett, Clairgeau, and Winter Nelis pear.

These lateral buds are spoken of as axillary buds, by Magness (230), who studied their time of differentiation, and Gourley (151) so regards them on what seems conclusive evidence. Yet Butler (56) says that they are really terminal buds on sessile spurs formed during the season in which the shoot is growing. He says that at the close of the growing season these buds will be found to be subtended by a rosette of leaves and not in the axil of a single leaf. To the fruit grower this would make little difference; but it is certain that with the apple a fruit bud is often formed in the axil of a single leaf. In the fall of 1919, at the Cornell Experiment Station, tags were placed on a considerable number of shoots each of which contained not more than one leaf at any node. In other words, each lateral bud on these shoots was in the axil of a single leaf. In the spring of 1920 at blossoming these were examined. On a Wagener apple tree, of twenty-two twigs marked, none contained bloom clusters. On a Rhode Island Greening apple tree, thirty-five twigs, that had been marked, contained four hundred and seventy-seven axillary buds of which ninety developed flower clusters. Eleven fruits were set from these. On a Wealthy apple tree, nineteen twigs, that had been marked, contained two hundred and forty-seven axillary buds from which forty-nine flower clusters developed, twenty-four fruits being set. This leaves no doubt that fruit buds develop in the axil of a single leaf with some apple varieties, and is in agreement with the observations of Kraus, Magness, Gourley, and other workers.

Gourley says such buds are of little commercial importance. But according to Kraus (207) varieties that form such buds, as well as those which set many fruit buds terminally on shoots, begin to bear young and seem more likely to be annual bearers. Such a generalization would not be justified, however, except after study of many varieties. There are certainly striking exceptions; for the Baldwin apple tree sets fruit buds on the terminal of twigs to a larger extent than do trees of most other varieties, and it is one of the varieties most liable to bear crops only on alternate years; and Wealthy, Wagener, and Oldenburg apple tend strongly to alternate bearing, and are among the varieties conspicuous for setting fruit buds on the terminals of twigs and in the axils of leaves; while Rhode Island Greening and Jonathan, varieties tending to bear annual crops, tend also to set many twig terminal and axillary fruit buds. In New York, however, considerable crops are borne by young Wealthy and Wagener apple trees from such buds, in some years when the crop from spur fruit buds would be light. Fruit borne so far out on the branches tends to bend and break them worse than does fruit borne on spurs from wood that is several years old. Further, the fruit may be borne so thickly along the twigs that much thinning will be required. These axillary buds generally bloom later than the spur or other terminal buds of the apple; and the fruit usually continues to be smaller even up to the time of thinning.

The fruit bud of the apple and the pear, whether a terminal or an axillary bud, opens into a thickened woody cluster base containing a whorl of leaves and a cluster of about five to eight flowers. In Figure 6, Number 1 is a part of a branch containing a weak and a rather strong spur, each two years old, the leaves having been removed, leaving part of the petioles. Numbers 2, 3, and 4 show how such spurs would look in the following summer, assuming that the terminal bud is a fruit bud. Until the spurs bear fruit, they grow

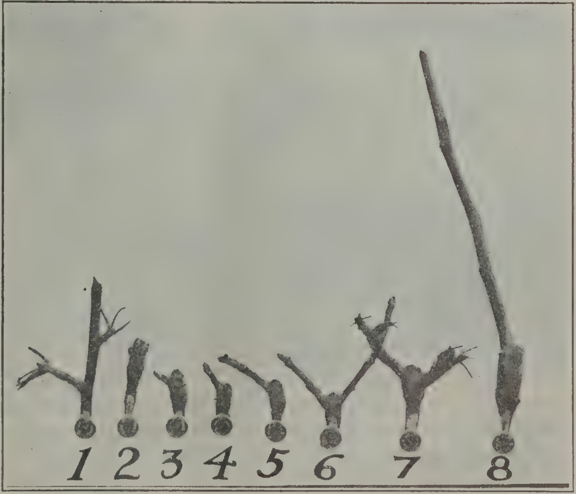

Figure 6. Apple spurs of different types and different ages.

longer each year; very seldom branching. In a year when blossoms are set, however, the new growth is from the side of the thickened cluster base. In the year the blossoms are borne on the cluster base, only a bud may form, as in 2, or there may be a short spur formed as in 3 and 4; while, under rather exceptional conditions, there may be a long growth like that of 8. Usually spurs like those at 3 and 4 do not form fruit buds during their first year, the year the fruit is borne; but, generally, the spur continues length growth in the succeeding year as with 5, and forms a terminal fruit bud. However, a spur sometimes forms a fruit bud the year it grows from the cluster base; that is, while the fruit is being borne. Thus, Wiggans (361) found in Missouri that, of spurs fruiting in 1913, 8.2 per cent bloomed again in 1914 with Gano, 8.5 per cent with Rome, and 15.8 per cent with Jonathan. Bradford (52) found with Yellow Newtown that bearing spurs occasionally form fruit buds. Sometimes, as at 2, 6, and 7, more than one bud grows from the same cluster base. As a result of this, the growth from an original spur may become even much more branched than that of 7.

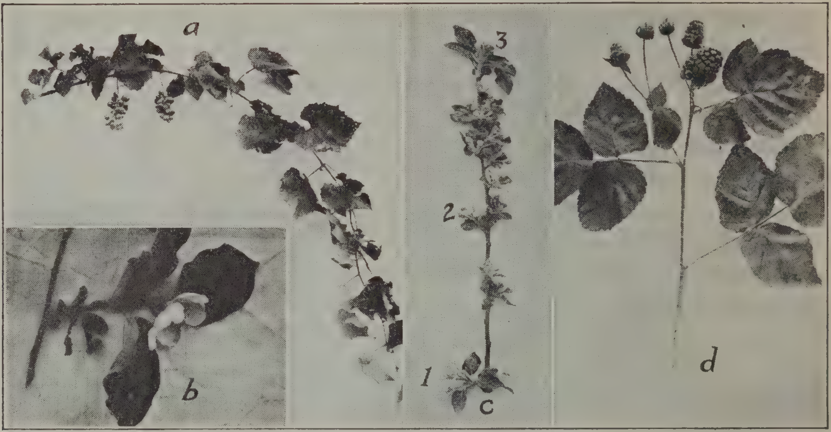

FIGURE 7. At *a* is a new shoot of the Clinton grape showing where fruit is located; *b*, a short fruiting shoot of the quince with a single terminal blossom; *c*, blossom clusters of Wealthy apple, *1*, from spur terminal bud, *2*, from twig lateral buds, *3*, from twig terminal bud; *d*, fruit cluster at the end of a shoot from cane of red raspberry.

The cluster bases from axillary buds are generally considerably smaller than those from terminal buds. With some of these, buds do not grow from the side and they die after the fruit is picked. However, with a considerable percentage, such buds grow; and the habit of forming axillary fruit buds does not seem, harmfully, to reduce the spur system of apple or pear trees. According to Yeager (365) the percentage of the spurs to flower decreases more or less rapidly with increasing age of the spur; depending somewhat upon the variety. And Wiggans (361) found in Missouri that most of the blooming spurs of the apple are between the age of three and seven years. Spurs are borne more thickly along the branches of some varieties of apples and pears than of others. This is probably because more of the axillary buds that are borne on the twigs fail to grow with some varieties than with others. Auchter (27) calls attention to the fact that the four or five buds at the base of a twig generally fail to grow into spurs or twigs. He thinks this is probably due to the fact that the first few leaves formed on a twig are generally small, and, therefore, likely to subtend buds weakly developed. He often observed a section near the middle of a twig where the buds failed to grow. This, he thinks, is due to the twig's having been subjected to a period of weather unfavorable for growth during which the leaves formed were small. Such leaves would subtend weak buds.

With the quince, the blossoms are borne singly on the terminal of new shoots as shown at *b* in Figure 7; while with the persimmon the flowers are borne laterally in the axils of the leaves of new shoots.

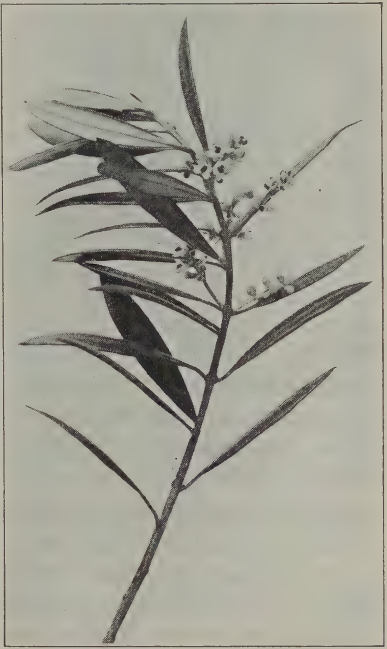

Figure 8. Showing the fruiting habit of the olive. The part beyond the distal flower cluster is the growth of the current season.

With the currant, lateral buds on wood of the previous season open into cluster bases about one eighth of an inch long to which are attached, usually, several racemes containing a considerable number of flowers. With the gooseberry, there is a similar cluster base bearing one or more pedicels with one to three flowers. With both there are small bracts opening from the same bud with the flowers.

With raspberries, blackberries, and dewberries, the flowers are borne in leafy clusters from axillary buds of the canes that grew during the previous season as shown at *d*, Figure 7. The main stems of the cluster may be from two or three to ten or twelve inches long. With the red raspberry, there may be a large terminal cluster of flowers borne on the cane during its first year. This is very common with varieties like Ranere, autumn fruiting varieties. The fruit is borne on the terminal of the cane in autumn and on shoots from lateral buds the next season.

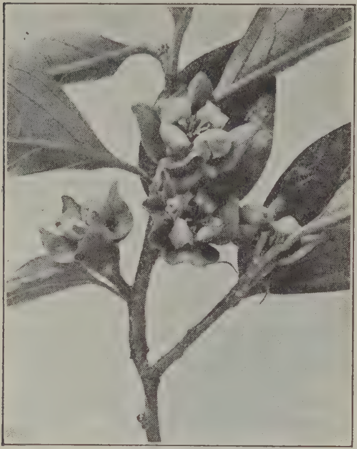

FIGURE 9. Pistillate flowers of the persimmon, borne laterally on wood of the current season.

With the grape, the flowers are borne on clusters at the nodes of the new shoots of the same season. With *Vitis Labrusca*, the flowers are generally at the first three to five nodes of the shoot, or, if the first leaf is a weak one, at three to five successive nodes, beginning with the second; while with some other species there may be a flower cluster at each of the first two leaves, or the second and third leaf, nothing at the next and a flower cluster at the next leaf, or at each of the next two; though often with this last type there are but two clusters to the shoot.

Age when fruiting begins. With raspberries, blackberries, and dewberries, fruiting usually begins the next summer after the plants are set, the amount borne increasing during two or three years while the root system is increasing in size. Gooseberries and currants generally bear well on new wood and may begin fruiting the next year after the plants are set; the amount borne increasing during the succeeding four to six years until the plants occupy all available space.

Healthy peach trees in the climate of New York are likely to set fruit buds during the second summer in the orchard, and to bear fruit, often a crop worth harvesting, during the third summer; bearing maximum crops at six to eight years of age. Where the summers are very long, as in California, these stages may be reached as much as a year earlier.

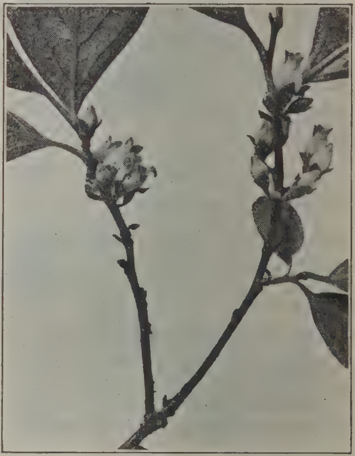

FIGURE 10. Staminate flowers of the persimmon.

Plum varieties vary much, there being so many species and types. Trees of the Japanese plum (*Prunus salicina*) fruit as young as do peach trees. Most of the American species fruit nearly as young. The varieties of *Prunus domestica* generally are not so early in fruiting, but they vary much. Thus, in New York, Reine Claude should bear a fair crop at five years of age, while German Prune will be a year or two later, Bradshaw still later, and some varieties may have borne but little at nine years of age. Trees of none of the plum varieties reach maximum bearing as young as do peach trees.

Sour cherry (*Prunus cerasus*) trees fruit nearly as young as peach trees, but are two or three years later in reaching maximum bearing; while sweet cherry (*Prunus avium*) trees seldom bear appreciable crops of fruit in New York before they are seven to nine years old or older.

Pears of the species *Pyrus communis* generally fruit but little in New York before the trees are seven to nine years old, though trees of some varieties, such as Clapp Favorite, fruit younger. Kieffer trees and trees of other hybrids between *Pyrus communis* and *Pyrus serotina* fruit rather young.

Trees of most varieties of apples in America fruit earlier than do trees of most varieties of pears. There is great variation, however. Thus, trees of a variety like Wagener may fruit even in the nursery, and generally fruit during the second or third year in the orchard; while trees of Northern Spy and Sutton may fruit but little before they are twelve to fifteen years old.

With all of the kinds mentioned and under all environmental conditions, maximum crops tend to be borne when the trees are as large as it is possible for them to be without injuriously shading each other. The age at which this maximum is reached, as well as that at which the tree begins to bear some fruit, is influenced by soil and climatic conditions. Where the summers are short, if the rainfall is abundant and the soil very fertile, except with the raspberry and blackberry, the plant may not begin to fruit as young as if conditions for growth were less favorable; but maximum fruiting will generally tend to be reached younger the more vigorous the early growth. If the water and the mineral nutrient supply is abundant and the growing season is long, the tendency is for both initial fruiting and maximum fruiting to be reached early.

All of these estimates as to the age when fruiting begins concern trees pruned but lightly while young. Severe pruning of young trees will delay initial bearing and maximum bearing.

Time of development of flower parts. While it does not seem necessary to trace in much detail the development of the flower parts of the different fruit species, it is of interest to know at what time the fruit buds begin to differentiate. Some early studies were made by Lazenby (214), Quaintance (279), and Waldron (345). One of the earliest and most extensive studies was made by Goff (144–147), who described the development of the buds of the apple, pear, plum, cherry, peach, quince, strawberry, raspberry, blackberry, cranberry, gooseberry, grape, and currant. He found the first discernible differentiation coming as early as July with some buds of the apple and pear, and as late as September or even October with others. Differentiation was discernible in early July with the plum and the cherry. With the peach, the differentiation into flower buds was discernible by September 14th and with the Clyde strawberry by September 20th. Buds of the Victoria currant began to show differentiation by August 3d; the Downing gooseberry by August 30th; the cranberry by August 31st. Goff found incipient flower development during late summer or autumn with the quince, raspberry, blackberry, and grape, though the differentiation was not so nearly complete as with other fruits. With fruits like these last, with which the flowers are borne either terminally or laterally on shoots of the same season, there is not convincing evidence as to whether or not the bud is always predetermined. With the strawberry the flower parts are not always formed during the season preceding blooming.

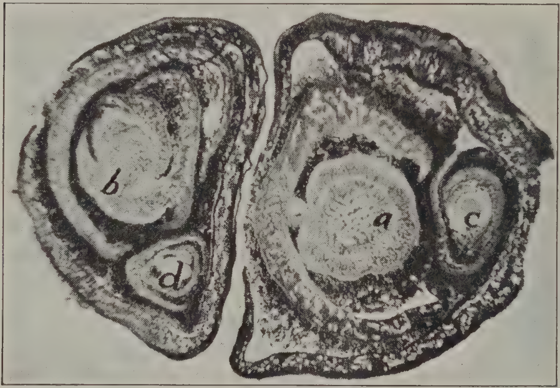

Figure 11. Showing a section across a Labrusca grape bud. There are within the bud scales a number of buds, the primary one being shown at *a* and the others at *b*, *c*, and *d*. (After Angelo.)

MacDaniels (222) found, in the climate of Ithaca, New York, differentiation beginning October 1st with Cumberland black raspberry; about January 1st with Golden Queen red raspberry and Columbian purple cane raspberry; and as late as March 3d, differentiation with the last two was still far behind that of black raspberry buds. With the Snyder blackberry, differentiation began apparently in August and flower parts were clearly developed in September. With Houghton gooseberry and Cherry currant, differentiation was about as early as, or a little earlier than, with the blackberry. With both black and red raspberries, when the canes were cut back severely, basal buds, that normally remain dormant, were caused to grow into rather long shoots terminated with clusters of flowers that opened later than the other flowers on the shoots. With blackberries, these basal buds when forced by severe pruning generally grew into vegetative shoots only. In other words, with the raspberry, but not with the blackberry, any bud on the cane seems to be potentially a fruit bud. However, at Ithaca, many of the raspberry shoots bear terminal flower clusters in the year they grow. It is possible that, on the shoots from these basal buds, flower-part differentiation may have occurred in the spring after growth started.

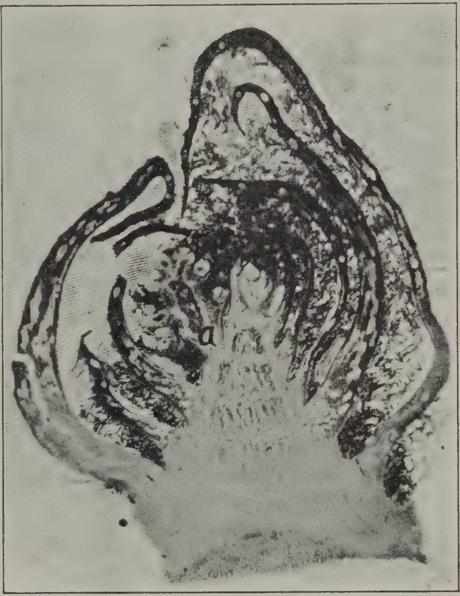

Figure 12. Longitudinal section of a Labrusca grape bud. Note the developing flower cluster at *a*. (After Angelo.)

Bioletti (759) found the flower parts of the grape, *Vitis vinifera*, formed during the season before the buds open. According to Gladwin (143) the grape, *Vitis Labrusca*, bud consists frequently of three distinct buds enclosed by the same scales, a primary or fruit-producing bud, a secondary nearly sterile bud, and a tertiary bud that expands only when the others have been killed, producing a sterile shoot. With young vigorous vines both the primary and secondary bud may grow, but with old vines generally the secondary bud grows only when the primary bud has been killed. Bioletti found that there may be even more than three buds in one set of scales. In Figure 11 is shown a cross-section of a Labrusca grape bud.

Drinkard (111) studied in Virginia the formation of fruit buds, with the apple, pear, peach, plum and cherry. With the apple, he studied several varieties and found but slight difference in the time of differentiation. Most of his work was done with Oldenburg. With that variety, each year, small projections on the crown could be observed late in June. By July 14th, the calyx was conspicuous; and the small protuberances near the base of the calyx cup indicated the stamen initials. With Kieffer pear, evidence of the formation of fruit buds could not be seen until about the middle of July; Lustre peach, the first week in July; Whitaker plum, the first week in September; Japanese plum, early in July, and Louis Philippe cherry, late in June. With the Oldenburg, the pistils began to develop early in August; and by the end of September the cavities of the ovaries could be discerned. By the end of October the filaments of the stamens had begun to form. There was slight development of petals before January 27th, when a pointed projection, rising apparently from the calyx, indicated the beginning of petal formation. There was renewed development in the anthers by February 19th. The development of the buds of the pear, peach, plum, and cherry was not very different from that of the apple, all being practically differentiated by November and making but slight changes until February. The Whitaker plum (*Prunus Munsoniana*) was a partial exception, differentiation not beginning until September, while development continued through December.

Bradford (52) studied the fruit-bud development of the Newtown apple in Oregon. He thinks that some confusion has arisen through mistaking a crown that may be observed during active growth for the first stage in fruit-bud formation. He says:

> The first evidence of fruit-bud formation lies in the rapid elevation of the crown into a narrow conical form, rounded at the apex, with the fibro-vascular connections and pith areas advancing concurrently. In the axils of the young leaves, already noted in connection with the undifferentiated bud, appear other protuberances which soon become blunt at the top, while at the same time other leaf protuberances develop rapidly higher up in the spiral and younger protuberances appear in their axils. The apical protuberance is differentiated last, but when it does take shape it is already larger than those previously laid down, apparently appropriating a larger mass of tissue in its formation. That this succession of changes is gone through with extreme rapidity is to be inferred from the fact that it was shown by a very small number of sections out of a great number examined from material gathered at weekly intervals.

In Oregon, the development with Newtown differs somewhat from that with Oldenburg in Virginia. He says:

> The earliest differentiation is visible during the first ten days of July. It may possibly vary from year to year to a very slight degree. Samples from material gathered throughout a period of three years show very little, if any, difference between the stages reached at a given date in different years, until well toward blossoming time, when the buds apparently become more responsive to external conditions. By the fifth of August the sepals, petals, and outermost cycle of stamens are easily recognizable. Sections from material gathered the middle of September show further development in the parts already mentioned; the petals

have become longer and wider; the stamens show, frequently, the bi-lobed appearance; in addition, the other two cycles of stamens have appeared and are well differentiated, and in many cases the carpels are already of fair size. The lateral buds of the cluster have, not uncommonly, reached the stage where the second and third cycles of stamens are suggested. Between this time and the last of November the most striking change is in the carpels, which by the latter date have enlarged considerably.

Material gathered the middle of February shows little or no change in the terminal blossom, but pollen mother-cell formation in the side buds is evident. During February and March the pistils begin to push up rapidly and the ovules appear. Petals and stamens appear to have completed their development and to be awaiting the expanding of the blossoms.

Wiggans (360) found, in California, differentiation of Bartlett pear fruit buds beginning before July 7th, but apparently with apricot, fruit-bud differentiation did not begin until early in August. Morrow (245) found at Davis, California, in the summer of 1923 the first signs of differentiation with Nonpareil almond, September 1st; Gravenstein apple, before June 11th; Royal apricot, August 10th; Early Richmond cherry, July 12th; the Napoleon cherry,

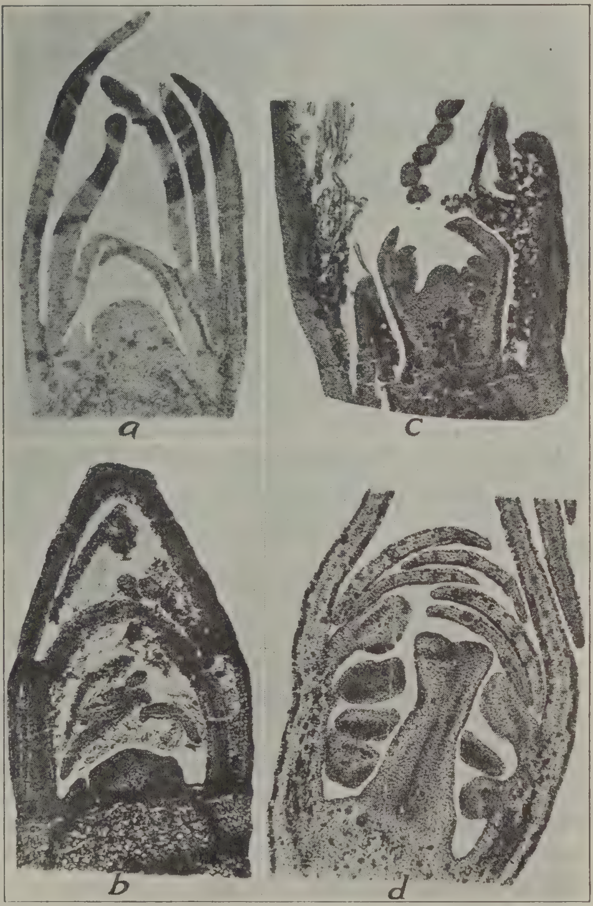

Figure 13. Showing development of flower buds of Napoleon cherry in California in 1923; *a*, June 20; *b*, July 3; *c*, August 17; *d*, September 1. (After Morrow.)

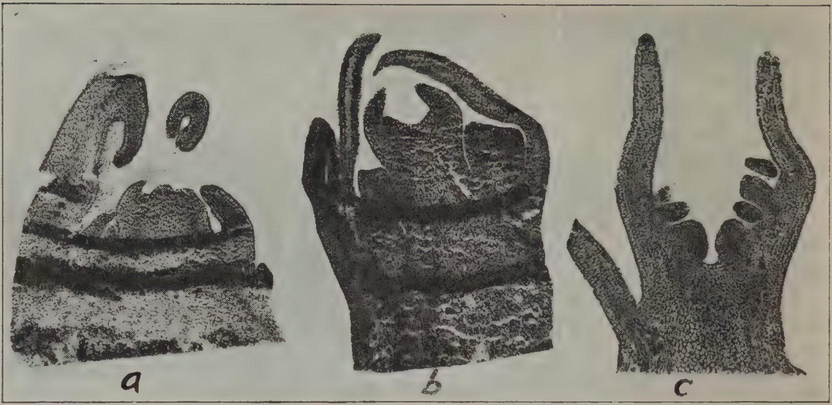

Figure 14. Showing development of flower buds of Gravenstein apples in California in 1923; *a*, June 7; *b*, July 11; *c*, October 13. (After Morrow.)

July 2d; Elberta peach, July 30th; Bartlett pear, before June 21st; Agen plum, August 17th; Wickson plum, after August 10th and before September 1st.

Magness (230) found that differentiation of axillary fruit buds with the apple is similar in nature to that of spur buds, but begins about three weeks later; in Oregon continuing slightly less advanced until blooming time.

Concerning the development of fruit buds from leaf buds Bradford (52) says:

> Distinct leaf buds, well differentiated, were found as early as May. The leaf buds differ from the undifferentiated in that the crown is flatter and broader, is not raised so high above the level of the embryo leaves, and scale bases, and has no swellings or very young leaves at its periphery. The amount of meristematic tissue is relatively less, and clearly defined tissue occurs closer to the growing point. All in all, the appearance presented strongly suggests a resting stage. Whether the bud can advance from this resting stage again and form a fruit bud in the same season is a matter for conjecture.

Experience with trees suggests that if conditions in the tissue are not favorable for fruit-bud formation at the time a bud is developing, it goes into a resting stage, after which it is seldom if ever caused to become a fruit bud. A possible explanation of the fact that, with long apricot shoots, fruit buds are found only on wood of the later seasonal growth cycles would seem to be that, in the vigorous shoots during the earlier growth cycles, nutritive conditions are unfavorable for fruit-bud formation and the buds enter a resting stage in which they are not caused to become fruit buds after nutritive conditions in the wood become more favorable. However, we do not know that this is true.

This problem, as to when a bud can be influenced toward becoming a fruit bud or a vegetative bud, is very difficult; since the same bud cannot be watched through the various stages of development. Such information should be of great assistance toward an understanding of the behavior of trees as to fruit-bud formation in different seasons. For example, with the Baldwin apple in New York in 1921, although the season considered as a whole seemed favorable for fruit-bud formation and most of the trees were not bearing a crop, very few fruit buds were formed on spurs; the bloom in the next spring being mainly at the terminals of twigs. If, with a bud, there were only a very short period when conditions determined whether it would become a fruit bud or a resting leaf bud, the explanation of such behavior as that of the Baldwin spurs might be that there was a short period when soil or climatic conditions caused the chemical nature of the tissue to be unfavorable for fruit-bud formation and that spur buds went into the resting stage, but that the terminal buds of shoots were developing after the chemical nature of the tissue had become more favorable for fruit-bud formation. It may be that when lateral and terminal buds form on long shoots, but not on spurs, in the bearing year of alternate bearing varieties, the chemical situation in the tissue early in the season, when there is rapid development of many young fruits, is unfavorable for fruit-bud formation, and the early developing spur buds go into the resting state as leaf buds, but that, later, when the lateral and terminal buds are forming on long shoots, conditions are more favorable for fruit-bud formation. However, we do not have conclusive evidence as to how long a bud remains in such a condition that it may be caused to become a fruit bud.

Generally, with most kinds large numbers of fruit buds are formed, and there is in the succeeding spring such a heavy bloom and the setting, at least temporarily, of such a large number of fruits, that there is an undesirable drain upon the reserves of the tree; and often, following such a heavy bloom, so many of the young fruits fall that the crop is smaller than would have been set from fewer blooms. On the other hand, with very vigorous young trees, with very weak old ones, or with trees that are bearing heavy crops, there is liable not to be enough fruit buds formed. The grower is, therefore, interested in avoiding the formation of excessively large numbers of fruit buds, and in being certain that a fair number will be formed each year.

Conditions that influence fruit-bud formation. It is interesting to note that the time at which fruit-bud differentiation begins is very near to the time at which length growth tends to cease. And we have seen that at this time the concentration of carbohydrates in the tissue rapidly increases; rather dry, hot weather apparently hastening that increase. Such weather may also cause a marked increase in fruit-bud formation, though it is improbable that *extremely* hot weather would have that effect.

Kirby (201) found in Iowa that, with the apple, earliness of differentiation of fruit buds is associated with early checking of growth by the tree. Wiggans (360) seemed to find the climatic differences in the coastal, interior valley, and foothill sections of California to cause very little difference in the time of first differentiation of fruit buds with the Bartlett pear, though in the foothill section initial fruit-bud differentiation seemed to be delayed with the Royal apricot. Probably the vegetative condition of the tree, as influenced by other environmental features than climate, would explain such a difference. Plentiful irrigation seemed to cause some delay in the initiation of fruit-bud differentiation, though difference in severity of pruning seemed to have but a slight influence, if any. Sectioning of buds is so laborious that, generally, not nearly enough are studied to give dependable information as to the effect of cultural practices or of other environmental features on the time of fruit-bud formation, unless that effect is very striking.

Ringing. We have seen also that ringing increases the carbohydrate concentration and generally reduces the nitrogen concentration above the ringed part. This practice has long been known to increase the formation of fruit buds and is sometimes made use of to increase the fruitfulness of trees in a home planting or in the testing of new varieties or seedlings. It is sometimes used commercially in grape growing, but in this case the purpose is not to increase fruit-bud formation. As practiced with fruit trees the ring of bark is removed at a time when the cambium is active and the bark can be removed without permanently injuring the cambium. A new layer of bark will generally form and the checking of the backward movement of the carbohydrates will be only temporary; but enough to stimulate fruit-bud formation to some extent at least. Howe (190) seemed to find that ringing cannot be depended upon to throw a tree into regular fruiting, and it certainly reduces the size of the tree. Alderman and Auchter (20) found similar results. Of course, the earlier fruiting would alone reduce the size of the tree even if the ringing did not directly produce that effect. Howe found ringing more liable to injure the trees of stone fruits than apple or pear trees, though any but young and vigorous apple and pear trees were liable to suffer injury. Drinkard (807) studied the healing of these ringing wounds. He found that a good moisture supply to the exposed cambium or newly formed bark is necessary for dependable healing. When he covered the ringed area with a band of paraffin paper or adhesive plaster, healing was always satisfactory. This experience may explain why healing of ringing wounds is more effective at some times than at others; differences in weather conditions at the time of ringing resulting in different amounts of injury from drying out of the cambium. From Drinkard's results it seems certain that with fairly vigorous apple trees ringing can be done with assurance that the wound will heal if protected. Shaw (316), working in Massachusetts, studied the effect of ringing, at different times in summer, Wealthy, Oldenburg, and Wagener apple trees seven years old that were planted ten feet apart each way. Ringing done at any time did not measurably influence the setting of fruit buds on trees bearing a crop; but that done May 31st and June 15th seemed rather strikingly to increase the number of fruit buds formed by trees not bearing a crop. Ringing July 15th and August 1st did not influence fruit-bud formation, but checked the growth of the tree more than did earlier ringing. Wound healing was better with trees ringed in May and June than with trees ringed in July and August. Except with the grape, ringing has only small practical importance. It is doubtful if one would often want to check the growth of young trees in order to cause earlier fruiting; for the more profitable crops would naturally be borne by larger trees.

With apples ringing generally causes little or no increase in the size of the fruit. In fact, because of the larger numbers, the fruits may be smaller. With grapes, however, the increase in size is often very marked; and Beach (41) found that it may improve the set of berries in the cluster. Palmer (261) seemed to find that the best time for ringing to increase the size of grapes is from three to four weeks after the bloom opens. Ringing will also hasten the maturity of the fruit; and grape growers in some sections ring in order to get the fruit to the market earlier. With grapes the ringing may be done so that the wound will heal; but where only the new shoot bearing the fruit is ringed, it may be desirable to have the influence that ringing causes on the development of the fruit prolonged throughout the season, in which case the cambium may be scraped. Of course, if all the shoots were so ringed, the vine would be killed; but if only a few of the shoots on each vine are ringed, although by keeping some carbohydrates from the roots the vine will be weakened, that weakening may not be serious, or even measurable.

Notching, bending, stripping, and root pruning. Branches or vines are sometimes treated in other ways in which the same principle is involved as in ringing. One of these is notching, a notch being cut through the bark just below or above a bud. This, of course, checks the movement of carbohydrates downward and increases the concentration at the buds above. Perhaps it may also inhibit the movement of nitrogen upward (Curtis, 95). If the notch is cut above a bud, that bud may open into a vegetative shoot the season of the notching, when otherwise it might remain dormant. That is, notching above a bud increases its vegetative activity, while notching below a bud reduces its vegetative activity and may cause it to become a fruit bud.

Bending the branches tends to encourage fruit-bud formation beyond the bend. Gardner (813) studied the effect of bending one-year-old apple twigs during the dormant season. More fruit spurs were formed on the terminal parts and fewer on the basal parts. Shoot growth was reduced at the outer end and increased at the basal part. The practice of bending will be treated more fully in Chapter 17.

Cutting out strips of bark lengthwise on the trunk or branch serves as a partial ringing, and may encourage fruit-bud formation. Cutting the roots (root pruning) reduces the water and mineral nutrient supply, checks growth, may cause accumulation of carbohydrates in the top, and generally causes an increase in fruit-bud formation. However, even if a treatment that checks the growth of a young tree increases the percentage of the buds to become fruit buds, it may not necessarily increase the amount of fruit borne. Generally the sooner the tree becomes large, the sooner it will bear profitable crops. While a young tree that is making good growth may set a smaller percentage of its buds as fruit buds, it may actually set a larger total number of buds and of fruits than will the more weakly growing tree. This is because there are more buds, spur buds and others, to form fruit buds. For not only is the tree larger, but there may be also fewer weak buds that remain dormant. Thus, Edminster (119) found that a larger percentage of lateral buds grow, giving a larger number of both shoots and spurs on the more vigorous twigs. This was found true whether vigor was measured by thickness or by length of twig.

Treatments that reduce both vegetative growth and fruit-bud formation. While the practices mentioned check growth and tend to increase fruit-bud formation, growth may be checked in a way to reduce fruit-bud formation. It is well known from experience, and Pickering (872) and others (782) have shown experimentally that one of the most serious checks to growth is a heavy crop of fruit; yet this tends to reduce the setting of fruit buds or to prevent it altogether during the year when the fruit is borne. According to Gourley (150) and Kraybill (212), it seems slightly to reduce the carbohydrate supply also; an influence that might be expected to reduce fruit-bud formation.

Removing leaves reduces growth by reducing the carbohydrate supply. It greatly reduces also the formation of fruit buds, and, if done after differentiation has begun, delays their development. Thus, Magness (231) found that the removal of the subtending leaves from a spur bud generally prevented its becoming a fruit bud. This he found true even though the leaves were left on the adjacent spur. And removal of the subtending leaf from an axillary bud, even when leaves are left with adjacent buds, seems always to prevent its becoming a fruit bud. In fact, such a bud tended not to start at all in the spring. Harvey and Murneek (161) found that defoliating apple spurs on June 15th in Oregon greatly reduced the percentage setting fruit buds, though six per cent to ten per cent of the defoliated spurs set fruit buds. It seems possible that with some spurs differentiation may have begun before the defoliation. Roberts (293) found with plum seedlings, apparently *Prunus nigra*, that removing a leaf inhibited flower-bud formation at that node and reduced the amount of adjacent storage tissue and the spur growth from that bud in the succeeding year. Cutting the midrib or removing part of a leaf reduced bud development at that leaf. Removing alternate leaves from a shoot reduced slightly flower-bud development at undefoliated nodes. In other words, the influence of defoliation was much the greatest at the defoliated node, but extended, in a small way, to other nodes on the shoot; perhaps to the shoot as a whole. Roberts (1123) found that cherry fruit buds on spurs with weak leaves and the smaller basal buds on shoots differentiate more slowly than others. It is of interest to know whether the bud is dependent upon its own subtending leaves for a sufficient supply of specific substances, such as carbohydrates and organic nitrogenous material; or whether the activity of the leaves may cause in the node a rather general chemical condition favorable to fruit-bud formation.

Nitrogen necessary for fruit-bud formation. From what has been said above, it may seem that the carbohydrate supply is the determining factor for fruit-bud formation. However, nitrogen also may be very important in determining fruit-bud formation. Thus, Alderman (550) in West Virginia found the percentage of fruit buds much greater on certain peach trees fertilized with nitrogen than on similar trees not so fertilized. Similar results with peaches were observed repeatedly in a rather large number of plats in the Ozark region of Missouri. Wiggans (361) found, with potted apple trees in sand and loess soil, that the application of nitrogen caused the formation of fruit buds. Remy (693) seemed to find with apples and pears that fruit-bud formation was not possible when the nitrogen content of the leaf was less than 1.25 per cent of the dry weight. Of course, it is possible that if other elements were deficient in the tissue, their use might encourage fruit-bud formation. Nitrogen, however, is most often deficient, and Remy found the buds more sensitive to variations in the nitrogen supply than to variations in the supply of other mineral nutrients.

Drinkard (595) and Barss (378) found that a very low moisture supply to potted dwarf apple trees greatly reduced fruit-bud formation. However, it is possible that a low water supply might reduce the nitrogen supply to the tree even when there was much nitrogen in the soil; and so, unless nitrogen determinations were made for the tissue, it is not certain that the reduction was due to inadequate water supply alone. Certainly a less severe reduction in water supply increases fruit-bud formation, with young trees at least; however, trees at the age when it is desirable for them to begin fruiting will generally set enough fruit buds when the water supply is abundant, if other conditions are satisfactory.

The carbohydrate-nitrogen relationship. Kraus and Kraybill (211) have emphasized the carbohydrate-nitrogen relationship in its influence on growth and fruitfulness. They described four classes of plants with reference to growth and fruitfulness and the carbohydrate-nitrogen ratio. Plants in Class 1 are high in nitrogen, low in carbohydrates, unfruitful and weak in vegetation; those in Class 2 are well supplied with both nitrogen and carbohydrates, and are highly vegetative, but unfruitful; those in Class 3 have a less abundant supply of nitrogen in relation to carbohydrates, and are less highly vegetative than plants in Class 2, but fruitful; those in Class 4 are low in nitrogen, high in carbohydrates, very feebly vegetative, and produce few blossoms, which tend to fall without setting fruit. The work leading to this classification was done with tomatoes. These workers have emphasized the fact that pruning, shading, cloudiness, insect, or fungous injury to the foliage, variations in the water supply, ringing, and other treatments may cause changes in the chemical condition in the tissue similar to changes that might be caused by differences in the soil nitrogen supply. They have called attention to the fact that chemical composition of the tissue, rather than the amount of growth made, probably determines fruit-bud formation. Thus, plants in Class 1 are very different vegetatively from those in Class 2; but their condition as to fruitfulness is the same and their chemical composition may be nearly the same. Class 1 conditions would generally be brought about by shading, or by reduction in photosynthesis caused by defoliation or by injury to the foliage such as insects, fungous diseases, or toxic substances might cause. It is conceivable, however, that a similar chemical condition of low carbohydrates and high nitrogen content of the tissue associated with temporarily weak growth might be found in the orchard. Thus, growth might be checked very early in the season by a low nitrogen supply or a low water supply; and the nitrogen and water might become abundant very soon after the checking. The initiation of a second growth coupled with the small leaf surface resulting from the checking might then reduce the carbohydrate supply, relative to nitrogen, to a level too low for fruit-bud formation. If, at the time the nitrogen and water supply became abundant, there should be a period of great cloudiness, this condition might be accentuated; and the buds on spurs might go into a resting stage before the carbohydrate supply would become large enough to cause fruit-bud formation. It is conceivable that the failure of Baldwin spurs to set fruit buds in 1921 may have been due to such a set of conditions. However, we have no conclusive proof that such a result could be so brought about unless the foliage were badly injured by insects or fungi.

Kraus and Kraybill speak of a rather general relationship between the nitrogen supply and carbohydrates in their effect on fruitfulness, and not of a ratio obtained by dividing the total carbohydrate content by the total nitrogen content. Other workers have stressed the ratio. We can be certain that the carbohydrate-nitrogen relationship is of importance in determining fruit-bud formation. If the nitrogen supply in the tissue is too low, fruit buds will not form. However, we have no proof that a reduction in the carbohydrate supply would be beneficial or that an increase in carbohydrates would accentuate the deficiency as to nitrogen. Such balancing of carbohydrates and nitrogen in the culture medium may be important as influencing the fruiting of fungi; but the conditions may not be the same in the plant tissue where most of the carbohydrates are insoluble. An increase or a decrease in the amount of starch may not greatly influence the active environment of the protoplasm. We know that unless the buds have nearly all gone into a resting state and unless the water supply is limited, an abundant nitrogen supply may cause the use of carbohydrates, by growth, to such an extent that fruit-bud formation may be inhibited. We can be certain also that the results of such treatments as pruning must be considered in relation to the nitrogen and carbohydrate supply. The effect of pruning trees having an abundant nitrogen supply might be different from that which would follow pruning if the nitrogen supply relative to the carbohydrate supply were low.

However, it seems probable that fruit-bud formation may be promoted by the presence in the tissue of some particular substance, perhaps an organic nitrogenous substance, or by some particular chemical composition or chemical environment of the protoplasm. The different nitrogenous substances or the different carbohydrate compounds may not all be of equal importance in determining fruit-bud formation. And other features than supply of total nitrogen or total carbohydrate may influence the formation of the determining substances. Thus, it does not seem improbable that the carbohydrate-nitrogen ratio in the tissue might in some cases be the same with low nitrogen and abundant water supply as with low water and abundant nitrogen supply; but that the chemical nature of the tissue might in other ways be very different. The total amount of organic nitrogenous material would probably be much larger in the latter case; and if there were a special organic nitrogenous substance that promotes fruit-bud formation, the amount of that substance might be larger. Experience suggests that such a condition of high soil nitrogen but limited water supply is very favorable for abundant fruit-bud formation.

It may be that, even if fruit-bud formation is determined not by the carbohydrate-nitrogen ratio, but by the amount of some special substance or by the general chemical nature of the tissue, as influenced by the amounts of nitrogen and carbohydrates, the carbohydrate-nitrogen ratio may be the best measure as to the amount of that substance, or as to that chemical nature, that we can use until we know more about the chemistry of plant tissue. Whether or not that measure is more helpful than measurement of such gross responses as shoot or trunk growth or leaf color can be learned only by experimental study. As yet we have the results of very few such studies and these are with buds under extreme conditions. The results of Hooker (181), of Hooker and Bradford (182), and of Kraybill (212) with fruiting and non-fruiting spurs, of Harvey and Murneek (161) with defoliated spurs, and of Kraybill with shading, in all of which cases fruit-bud formation was reduced and the carbohydrate-nitrogen ratio seemed to be narrowed, and those of Kraybill with ringing, which increased fruit-bud formation and widened the carbohydrate-nitrogen ratio, suggest that when the nitrogen supply is not unusually low, fruit-bud formation is increased rather uniformly by widening the carbohydrate-nitrogen ratio. And yet the evidence is far from being convincing. Thus, ignoring some inconsistencies and uncertainties of the others, the results of Harvey and Murneek, which seem to be the most extensive to be found with any one pair of conditions, present an interesting difficulty. Defoliating the spurs greatly reduced fruit-bud formation and apparently narrowed the carbohydrate-nitrogen ratio. This narrowing seemed to be due to increase in the amount of nitrogen in the tissue and reduction in the amount of polysaccharides; but the amount of reducing sugar was increased as much as was the amount of nitrogen; and total sugars seemed to be increased.

Total carbohydrates was but slightly influenced by the defoliation. At least two questions present themselves. First, may not the slight change in carbohydrate-nitrogen ratio be insignificant compared with other possible chemical and physiological changes caused by such a severe treatment as defoliation? Second, which are the more important determiners of fruit-bud formation, the rather inert polysaccharides or the more active soluble sugars? Further, in determining total polysaccharides, it is necessary to hydrolyze in weak acid, and we do not know how much of the material thus obtained is merely a part of the cell wall and cannot be considered as part of the reserves of the plant.

Harvey (158) suggests that very small differences in the carbohydrate-nitrogen ratio may check or promote growth. If that were true, very small differences might determine fruitfulness. In the work of Kraus and Kraybill (211) different series of plants, among which there were rather wide differences in the carbohydrate-nitrogen ratio, were described as fruitful. Until we have learned for each kind of fruit the maximum and minimum carbohydrate-nitrogen ratios that may be found in tissue forming fruit buds abundantly, we shall not know how to interpret results with such extreme influences on fruit-bud formation as defoliation, ringing, or the bearing of very heavy crops.

Other possible measures of potential vegetation or fruitfulness. It may be that determinations of the osmotic concentration of the tissue will give as much information as to when it has reached a condition favorable for fruit-bud formation as will analyses for the different carbohydrates and for soluble and insoluble nitrogen. However, we have no assurance that it will; for, while the condition of vegetation influences the osmotic concentration, it has not been determined that the rate of increase in concentration, due to reduced vegetation and consequent accumulation of soluble substances, will be measurably different whether the check in vegetation is due to an inadequate nitrogen supply, a low water supply, or a large crop of fruit. The effect on fruit-bud formation would, of course, be very different, the rather low water supply with adequate nitrogen generally favoring fruit-bud formation and the other two conditions opposing it.

Heinicke (169 and 171) finds, at least under many conditions, that catalase activity, the ability of macerated, neutralized tissue to decompose hydrogen peroxide at constant temperature, is generally greater under conditions favoring vegetation. Thus, when nitrogen is applied to trees growing in sod or when such trees are pruned rather severely so as to increase vegetation, catalytic capacity is appreciably higher. In fact, such capacity in the tissue of the twigs is higher rather soon after the nitrogen is applied. In all positions favoring vegetation, in so far as the studies have gone, catalytic capacity was found higher than at other positions. It is higher at the apex than at the base of a twig or a shoot and higher below than just above a ring or a notch. It is also higher in summer in the non-fruiting than in the fruiting year of alternate-bearing trees; but lower in the following winter.

Since we do not know the explanation of catalase activity, we cannot use it scientifically except as we would use any other unexplained reaction, by studying its response to every environmental feature in which we may be interested. If it should be found, under all probable environmental influences, a dependable measure of the condition of vegetation in the tree, it should be of great value in physiological study. Very little tissue is required and scores of determinations can be made in the time required for one nitrogen determination. Catalase studies may, therefore, come to be a means of making chemical studies in the tissue more effective. Thus, for chemical studies to tell much as to the composition associated with fruit-bud formation, the tissue should be taken at measured stages of vegetation. Due to the ease of making determinations, the catalase activity associated with a condition in the tissue favorable for abundant fruit-bud formation might be rather easily learned for individual shoots, parts of shoots, or spurs. Then large numbers of shoots, nodes, or spurs, in the condition when fruit buds would be initiated in considerable numbers, could be gathered and detailed analyses made for different nitrogenous and carbohydrate compounds (in so far as there are dependable methods). Knowing the chemical compositions of such fruitful tissue gathered at just the right time, it might be found easier to determine the effect on fruit-bud formation of variations from that composition. However, it may be found that catalase activity is too greatly influenced by conditions that do not influence fruit-bud formation and that it cannot be used in the way suggested.

We can agree that, in studying the influence on fruit-bud formation of fruit thinning, the application of fertilizers, pruning, and climatic differences, possible changes in the chemical nature, particularly as to carbohydrates and nitrogen, must be considered. However, possible chemical changes will not be the only feature or the most important features influencing the amount of fruit borne. The mere influence on the size or possible bearing surface of the tree is often the most important consideration. Thus, in pruning, the possible bearing of a tree may be greatly reduced without appreciably influencing the tendency of the wood left to be fruitful. These subjects will be discussed after problems of fruit setting have been considered. Much of the work of Kraus and Kraybill and others concerned the setting of fruit from the flowers to a greater extent than it concerned the formation of fruit buds. However, since the water supply is of great importance in determining fruit setting, treatment of that subject will be deferred until the various features that influence the water supply to a fruit or a flower have been discussed.

Summary. With the peach, apricot, plum, and cherry the fruit buds are generally axillary buds, though some of them may be borne laterally on very short twigs, generally called spurs. Sometimes with the cherry the terminal bud of a very weak spur may be a fruit bud, the spur dying after the fruit is borne. While most of the fruit buds of the apple and pear are on the terminals of spurs or twigs, some varieties very commonly bear axillary buds and most varieties bear such buds sometimes. With the quince, a single flower is borne terminally on a shoot of the same season, while with the persimmon and the grape, the flowers are borne laterally on such shoots. With the gooseberry and currant, a cluster base supporting one or more flowers or racemes opens from a lateral bud. With the raspberry, blackberry, and dewberry, leafy clusters open from lateral buds of canes that grew during the previous season. Fruiting begins during the first few years after planting with the gooseberry, currant, raspberry, blackberry, dewberry, peach, Japanese plum, and sour cherry. The sweet cherry and the pear tend to be the latest in coming into bearing, though some varieties of pears bear rather young. Apple varieties vary from those which will bear during the first three or four years in the orchard to those which are among the fruits latest in coming into bearing; even trees with little pruning bearing in some climates very little until they are ten or twelve years old. With the apple, pear, peach, apricot, plum, cherry, gooseberry, currant, and the quince, flower parts seem normally to be formed in the bud during the summer preceding bloom or not at all. With the strawberry, raspberry, blackberry, and grape, there is positive evidence that flower parts form during the preceding summer, but, perhaps, there is not conclusive evidence that such differentiation may not sometimes be delayed until late winter or spring preceding blooming. The supply of nitrogen may be too low for fruit-bud formation, but such a condition is not very common. It is much more common for the supply of nitrogen to be low enough to cause the blossoms to fall without setting fruit. It is the tendency of a very high nitrogen supply to encourage vegetation and reduce fruit-bud formation, provided the water supply is abundant, but under most conditions a high nitrogen supply does not prevent adequate fruit-bud formation with mature trees. In fact, with trees old enough to bear profitable crops, it is not generally possible, by use of nitrogen alone, to prevent excessive formation of fruit buds, if during June and July there are several weeks of high transpiration and rather low soil moisture. Treatments, like ringing trees or branches, notching below a bud, and bending of branches, that tend to increase the carbohydrate supply to parts of a tree, tend also to increase fruit-bud formation. High transpiration with limited water supply, unless the conditions are extreme, tends also to increase the supply of carbohydrates and to increase fruit-bud formation. All of these treatments that encourage fruit-bud formation tend to increase the carbohydrate-nitrogen ratio. Heavy fruiting, shading, and defoliation tend to narrow the carbohydrate-nitrogen ratio and to reduce fruit-bud formation. As to whether or not the reduction in fruit-bud formation is due entirely to the narrowing of the carbohydrate-nitrogen ratio, there is not convincing evidence.

CHAPTER 3

THE REST PERIOD OF FRUIT PLANTS AND SEEDS

With all deciduous fruit trees there is a period when the part above ground will not grow even when temperature and moisture conditions are favorable for growth. The term "dormancy" is often applied to this condition; also the term "rest period." In this discussion the term "rest period" will be used to designate the period when the plant will not grow even though temperature and moisture conditions may be favorable; while the term "dormant" will be used to indicate inactivity due to any cause. (This terminology is used merely for the sake of clarity. It is not assumed to be better usage than the reverse would be. Thus, Crocker and workers in his laboratory use the term "dormancy" with the same meaning that the term "rest period" is given here, and the propriety of such usage cannot be questioned.) By the terminology here used, an apple tree might be said to be dormant in February because the temperature is too low for growth, while it might be dormant in December both because the temperature is too low for growth and because the tree is in the rest period and would not grow even if the temperature were favorable. In other words, where the winter is long, the tree may remain dormant long after its rest period has ended.

The beginning of rest. With deciduous trees the rest period begins in summer soon after length growth has ceased. With kinds such as the apricot, with which the growth of a season is cyclic, the rest period begins soon after the ending of the last growth cycle. The beginning of the rest is hastened by conditions unfavorable for growth, such as drought or insufficient nitrogen supply. The tissue seems to go into the rest gradually. During a short time after length growth has ceased, a period of very wet weather will result in a renewal of growth; in some of the shoots, at least. However, if the wet weather does not come until several weeks after growth has ceased, then, with some kinds, new growth is not likely to result unless the first growth has been very weak. With a tree of fair vigor, if there is growth, it may be in the form of water sprouts on the lower parts of large branches where the rest period begins later. Likewise, if just at the time growth ceases, the tree is pruned severely or the leaves are removed, new growth will result, while, if the pruning is done later in the season, new growth may not follow.

The rest does not begin for the whole tree at the same time. Its beginning in each shoot seems to be indicated by the time its length growth ceases. Casual observation suggests that an increase in the water supply is most likely to result in renewed growth in those shoots that have most recently formed their terminal buds.

Howard (188) thinks that the rest period begins as a result of the inhibition of enzyme activity due to the over-accumulation of the products of their work. He seems to mean by this anabolism, for he says, "With a decreased water supply and a greatly increased deposition or accumulation of carbohydrates, enzyme activity is soon checked if not almost entirely inhibited." Curtis (92) suggests that perhaps one of several causes of rest is the accumulation of inhibiting by-products of katabolism. Klebs (203) thinks that the rest period results generally from lack of mineral nutrients, or, perhaps, a low proportion of mineral nutrients to carbohydrates. Thus, with a number of species of trees from the tropics there is cyclic growth; sometimes several brief periods of rest in a year. He was able to cause growth to continue more than a year without rest. Apparently only when the soil began to be exhausted, or when daylight was too short, was there rest. It is certain that the time of entering the rest period can be greatly delayed if the supply of water and mineral nutrients can be maintained at near the optimum. Perhaps it would be within the truth to say that a low water or mineral nutrient supply to the growing points starts the changes in the tissues that result in the rest period. It does not necessarily follow that the rest period is one during which there is being gradually established a ratio between nitrogen or other mineral nutrients and carbohydrates most favorable for growth.

There has been very much study by men seeking a physiological or chemical explanation of the rest period. Theories are strongly supported by some workers, but there is no agreement and no conclusive proof concerning any view. The chemical nature of plant tissue is so complicated that it will probably be very long before an explanation of this phenomenon is possible. It would, therefore, throw no light upon any horticultural problem to review all of the literature concerning the physiological explanation of the rest period, though a description of the actual behavior of the tree during that period may be very useful.

The ending of the rest period. As the beginning of the rest period is very gradual, so also is the ending. Thus, in the climate of Missouri, if peach twigs are taken from the tree in November or early December and the ends placed in water in a warm room, the buds will not grow; but if they are taken in late December or early January, they will grow slowly;

while if they are taken in February, they will grow much more rapidly. In the lower latitudes in which deciduous fruits are cultivated, growth may begin in spring before the ending of the rest is complete. This may explain why the opening of the buds is more sluggish, with some species, in low than in high latitudes.

The time of the ending of the rest period varies greatly with different species. Howard (186) placed in a warm room twigs of 234 species collected October 28th to November 4th. Of these, 42 species grew during the first 9 days and 125 finally grew. Of 283 species taken January 8th to 10th, 142 grew during the first 9 days and 244 finally grew. Of 63 species taken on February 26th, 49 began to grow in 9 days, 7 required a longer period, and 5 never grew. Of fruit species whose twigs were taken October 20th to November 4th, leaf buds of *Prunus avium* were opening in 5 days, flower buds of *Prunus Cerasus* in 13 days, leaf buds of *Prunus domestica* in 23 days, while *Prunus Persica* would not grow, though they began growth readily when taken January 8th to 10th. Leaf buds of *Pyrus communis*, taken October 20th to November 4th, were opening in 15 days, of *Pyrus Malus* in 22 days, of *Ribes nigrum* in 16 days, of *Ribes sativum* in 14 days, of *Rubus idæus* in 9 days, of *Vitis vulpina* in 34 days. Varieties of these species vary in the length of their rest periods. Thus, some varieties of peaches have markedly longer rest periods than others (967, p. 271). Varieties of the Peen-to and Honey groups seem to have very short rests. But Howard's results indicate that most of the species studied that are important for their fruit have relatively short rest periods. The species tested of *Carya*, *Castanea*, and *Juglans* (the northern nut-bearing trees) seemed to have rather long rest periods. The species of *Corylus* used would not grow when taken October 20th to November 4th, but would grow readily when taken January 8th to 10th.

Hodgson (179) found the sweet cherry (*Prunus avium*), the apple (*Pyrus Malus*), the pear (*Pyrus communis*), and some varieties of *Domestica* plums grown in California, to continue partly in the rest until rather late in the winter. The late blooming of these kinds in that State suggests that they are still partly in the rest when they bloom in April. They are among the latest blooming kinds; although at higher latitudes, such as that of Ithaca, New York, the sweet cherry and the pear generally bloom earlier than the peach. In California the pear and apple tend to bloom later in the warmer than in the colder sections of the State. Hodgson seemed to find the rest period of detached twigs of the almond ended by November 20th; of Japanese plums, by December 20th to January 26th; of the apricot, by January 1st; and of the peach, by January 9th to January 26th. Yet in California all these fruits, blooming in February and March, seem to respond to growing temperatures much less rapidly than they do in sections where the winters are longer. It is probable that the rest period of detached twigs is shorter than that of twigs on the tree.

It has been suggested that any treatment, such as severe dormant pruning, fertilizing with nitrogen, or good cultivation that prolongs the growing period in summer, will delay the beginning of the rest period. With the peach, at least (966 and 967), the end of the rest period is later for those trees whose growth has continued later in summer; and, in interior sections at latitudes as low as 36°, maintaining high vigor in peach trees may delay the swelling of the buds and even the opening of the bloom; occasionally enough to avoid the loss of a crop from frosts in late winter or early spring.

It should not be assumed, however, that the rest period ends merely after a reasonably definite period of time for each species. It is probable that ending in mid-winter or late winter results partly from exposure of the plant to low temperature. Coville (80) found with the blueberry (*Vaccinium corymbosum*) and with some other woody plants that when they were kept continuously in a warm greenhouse they would not start growth normally in spring, some remaining dormant more than a year. If they started at all, it was after the ends had begun to die back; this great weakening of the plants seeming to bring them partly out of the rest period. Plants of the same species, kept out of doors during most of the winter or kept for a few months at temperatures of 31° to 36° F., made normal growth when brought back into the greenhouse. It seems that a temperature below freezing is not necessary to cause the normal ending of the rest. Crocker and others working at Chicago University have generally found that the after-ripening of seeds having a rest is more satisfactory at 5° C. or at 10° C. than at freezing temperatures. It seems possible that in a region where the winter temperature is continuously between 32° and 50° F., the internal changes that constitute the ending of the rest period may proceed more rapidly than if, during much of the time, the temperature were below freezing. However, I know of no data concerning this question. Certainly, in sections where the winter temperature is high, the rest period ends more slowly than where the winter temperatures are continuously rather low.

With seeds of the *Cratægus,* which germinate more quickly after being held at a temperature of about 5° C. for two and a half to three months, Davis and Rose (100) found that, if they are removed from the low temperature to the temperature of the greenhouse before they have completed the after-ripening period, the ripening process is stopped or greatly delayed. As to whether or not the number of days of low temperature required to break the rest period of trees is greater or less when periods of high temperature intervene, there seems to be no data. We know, however, that, when the winter temperature is rather high during much of the time, the rest period approaches an end more slowly. That is, we do not know whether or not the warm days throw the tree back into a more profound rest period; but we can be certain that the changes by which the tree approaches the end of the rest period proceed very slowly during the warm days. Thus, at lower latitudes the beginning of the rest may be as early in summer as at higher latitudes, yet the trees may be only partly through when spring comes, while at the higher latitudes they may be through by very little after mid-winter. Phillips (1109) has shown that between latitude 32° and 38° the blooming date of fruit trees seems to be delayed by their being still partly in the rest period. This may be of considerable practical importance in reducing injury from late spring frosts.

Coville found that the plant may partly emerge from the rest without a period of chilling if it becomes very weak. It is sometimes broken in summer by a serious drought, or by injuries to the tree, such as girdling, which reduce the water supply to the top. Sometimes, when, on account of such injuries or dry weather, the tree ceases growth very early in summer and perhaps loses a part of its foliage, there may be autumn bloom. This condition is rather common with some varieties of cherries and is to be observed sometimes with the apple and with some other fruits.

Special treatments that break the rest period. With the potato, Appleman (22) found that removing the skin will break the rest period, and when a potato is cut during the rest the buds near the exposed surface will grow if suberization of this surface is prevented. Coville (80) found that the rest period of a bud of fruit plants could be broken by cutting away the part of the branch above it, by ringing closely above it, or by rubbing the stem around it with a smooth knife handle. It may be broken before its normal ending also by treatment with ether or other anæsthetics (Johannsen and others), by desiccation, immersing in warm water, and a number of other methods. Thus, Howard (186 and 187) was able to force growth during the rest in twigs by the above methods and by immersing in weak solutions of sodium nitrate, potassium chloride, and copper sulphate, and by dipping in a paste of manganese dioxide.

Molisch (241 and 240) found that smoke from tobacco or even from paper will break the rest; he also found immersing in water at 30° to 35° or even 40° C. effective. This method has come to be used to a considerable extent by European gardeners in forcing plants into bloom for early trade. Weber (351, 352, and 353) found the rest to be broken by acetylene gas, by immersion in a solution of potassium nitrate, sodium nitrate, hydrogen cyanide, or hydrogen peroxide; and by exposing tissue to Röntgen rays. He describes, besides these methods, a number of others which have been used more or less successfully by different workers in breaking the rest. Some of them are, injury near the bud caused by pushing a pin into the tissue at its base, exposing to radium rays, drying, and defoliation. He uses the term "first rest" for the time when the plant is gradually going more deeply into the rest, "mid-rest" usually in late summer and early fall when the rest is most profound, and "later rest" during that part of the winter when the plant is gradually emerging from the rest. Treatments to break the rest, he says, are gradually less effective from the beginning of the first rest to the mid-rest and gradually more effective from the most profound part of the mid-rest until the plant has completely emerged.

Klebs (203) brought potted beech trees out of the rest by exposing them to continuous electric light in rooms from which sunlight was excluded; the time required in such an artificially lighted room, to cause the plant to resume growth, was short in September and gradually longer until October or later, then gradually shorter until February. Garner and Allard (1000) grew potted tulip trees (*Liriodendron tulipfera*) in a greenhouse, which, beginning early in September, was electrically illuminated from sunset until midnight, and others in a greenhouse with normal lighting. The former resumed growth which continued through the winter without abscission of the leaves, while the latter soon lost their leaves and remained dormant through the winter.

Howard (188) found that the treatments which break the rest period increase the activity of diastatic, proteolytic, fat-splitting, and oxidizing enzymes. He does not conclude, however, that recurrence of growth results from the accumulation of enzymes, but suggests that the enzyme activity may result from protoplasmic activity stimulated by the treatments. Coville (80) thinks that the rest is broken when protoplasm becomes more permeable and enzymes come in contact with storage material.

Tissue concerned in the rest. With trees whose growth has been checked in early summer, by severe drought or other injury, if there is wet weather in late summer or early autumn, there may be a renewal of cambial growth followed by very serious injury from early winter freezes. Whether or not there has been a breaking of the rest period in this case, we do not know. Most observations concerning the rest period have been with buds. In general, however, cambial growth in summer ends rather soon after length growth ceases (Knudson, 206), and, except following unusual moisture conditions, it is not resumed until length growth starts in spring; or a little later. And renewed cambial growth does not seem to occur in late summer except following conditions, such as severe drought, that would tend to break a rest period, or following an injury, such as removal of bark. Thus, while there is need for study along this line, it seems probable that there is a condition of rest that must be broken before cambial growth can be resumed. Howard's results suggest this conclusion. In studying the increase in diastatic activity caused by such treatments, as etherization, that break the rest period, he scraped the bark and cambial region from the treated twigs, grinding it and placing five-gram samples of this ground material with twenty-five cubic centimetres of two per cent starch paste. Naturally, five cubic centimetres of this material contained very little material from buds; and it seems probable, though of course not certain, that the increased enzyme activity was due to a change in more tissue than the buds alone. Coville (80) caused a single bud to grow by rubbing the bark around it. He did not rub the bud itself, and so the influence of the rubbing, it seems, must have been on twig tissue first.

While it seems probable that the resting condition is in the tissue around the bud as well as in the buds, it is certain that different parts of a plant do not necessarily end the rest period at the same time. Thus, Coville found that when a part of a plant was chilled and a part kept in a warm greenhouse, this last part would remain dormant after the chilled part had started into vigorous growth. And in latitudes below 36°, in interior sections, the vigorous growth on a pruned branch of a peach tree may remain nearly dormant after the weaker growth on an unpruned branch has come into bloom.

Curtis (92) finds with *Ligustrum ovalifolium*, *Prunus cerasifera*, and *Cornus stolonifera* that roots form from cuttings apparently as readily while the twigs are in the resting stage as when they are not. Cuttings taken in October rooted at once, but leaf growth would not begin until about March, while cuttings taken on December 8th rooted and were in leaf within two weeks (more than two months before those taken in October). Of course, it might be said that roots from the cut end might result because the rest period has been broken there by the injury. However, this could hardly be said of the roots that formed some distance from the end. Then it is known that, if moisture conditions are favorable, root growth continues throughout the summer after the top is in the rest period. It seems that not only is there no rest period for roots and that they grow whenever soil, temperature, and moisture conditions are suitable, but even the resting twig may send out roots. In other words, whatever the condition in the twig that prevents or inhibits twig growth during the rest period it does not seem to prevent or inhibit root growth. Of course, it is conceivable that, with the roots, the rest is at a different time from that of the tops; possibly in early summer when root growth tends to be slight.

Importance to the tree of the rest period. One benefit of the rest period to the tree is evident. If growth should occur in autumn or early winter whenever the temperature is favorable, a tree would seldom survive a winter. We have seen, also, that, in sections where the winters are short and so warm that growth starts before the rest period is completely ended, the opening of leaf and bloom buds is less rapid. The trees are thus in less danger of being pushed into growth by the warm periods, common in winters of such latitudes, to be killed by cold periods following. Since the roots are beneath the soil, where they are protected from very low temperatures or from sudden fluctuations in temperature, they are not in need of such insurance against growth at times when there is danger of freezing.

The pollination problem may be complicated by the rest period, since different varieties do not have equally long rest periods, and varieties that bloom together in the North might not bloom together in the South where differences in the length of the rest period might influence the blooming time. Discussion of the relation of the rest to climatic responses will be found in Chapter 20.

Rest or delayed germination with seeds. Some seeds have a rest period resembling that of twigs. Howard (187) seemed to find that of 122 species studied, 75 per cent had rests. According to Crocker (86) there are two general ways by which seeds are caused to rest. By one the seed is temporarily prevented from growth by enclosing structures, such as seed coats, that hold out something necessary for growth or hold in something that inhibits growth; a hard covering may exclude water; seed coats may reduce the oxygen supply to below the minimum for germination. By the other, the seed has a resting embryo. This seems to be common among plants of the family *Rosaceæ,* to which most deciduous fruits belong. With these plants the rest is broken by exposure to low temperature. Crocker and workers in his laboratory generally found a temperature of about 5° C. the best at which to hold such seeds. A few weeks or a few months at this temperature may be necessary.

Davis and Rose (100) found with *Cratægus mollis* that, under ordinary conditions, the seeds will not germinate as soon as the fruit is ripe, but require a latent period of one or more years. When the seeds were kept moist from the time of removal from the carpels and held at 5° to 6° C., they would germinate in two and a half to three months. No progress toward the ending of the rest was made when the temperature was as low as −2° C., and progress was stopped, or greatly retarded if the seeds were placed at temperatures much above 10° C. before the rest was completely ended. Crocker and Harrington (87) found temperatures of 5° C. and 7° C. good ones at which to hold peach seeds until the rest is ended; Jones (198) and Pack (260) found similar results with sugar maple and juniper seeds. Rose (294) found with elder (*Sambucus canadensis*) seed that drying is very injurious. Stratifying these dry seeds and leaving them out of doors over winter caused a fair germination. Rose found that the seed of the European red raspberry (*Rubus idœus*) is probably prevented from germination by the great strength of the endocarp. Seeds would germinate well after being soaked in concentrated sulphuric acid for two hours. A rather low percentage of germination was obtained by stratifying the seed and leaving it out of doors or even at temperatures as high as 15° to 20° C. Tukey (337) found with blackberry, dewberry, and raspberry better germination of seed soaked two to four hours in sulphuric acid, after having been held from November to January in a moist position at 34° to 38° F., than with seed held in a similar position, but not treated with acid. The acid treatment was of no value with seed held at room temperature in a dry condition.

Nurserymen have for many years been studying the best methods of treating seeds for the growth of fruit-tree stocks, and as a result of such experience have generally come to use practices in agreement with the principles discovered by Crocker and his associates. Harrington and Hite (157) found a temperature of 5° to 10° C. favorable for after-ripening of apple seed; and seeds from fruit held in cold storage at a temperature of about 0° C. germinated well. The larger growers of apple seedlings soak the seeds for several days and put them in sacks between chunks of ice for at least thirty days. It is probable that the temperature in such a position would be very close to 5° C., that found to be best for after-ripening of many seeds. Tukey found a similar practice to cause much better germination with apple and pear seeds than when they were not after-ripened in such a moist, cool position.

Tukey studied the after-ripening of peach, plum, and cherry seeds in relation to practices by nurserymen in New York. He found the most effective after-ripening in moist positions at temperatures near 5° C., his results agreeing with those of Crocker and Harrington. He seemed to find dried seed to after-ripen and germinate more satisfactorily than seed never permitted to dry after removal from the flesh. And he says that nurserymen prefer dry seed two years old. Freezing was not beneficial in after-ripening and was sometimes injurious. Similar results were obtained with some varieties of cherries and with Wild Goose plums (*Prunus Munsoniana*), but with some varieties of cherries and plums the seed could not be caused to germinate well by any treatment used, many of the seeds being abortive.

Summary. Deciduous fruit plants have a rest period during which neither leaf buds nor flower buds will open, even though moisture and temperature conditions may be favorable. Some tropical plants generally have a brief rest, but it is not certain that it is of the same nature as that of deciduous trees. It certainly is not so profound, and growth is generally resumed as soon as weather conditions become favorable. With deciduous plants this rest period is not identical with the period when the leaves are off. It is a period when they will not respond to favorable conditions for growth; beginning in summer soon after length growth ceases and ending very gradually during the winter, generally earlier at higher than at lower latitudes.

Growth response to favorable weather conditions is more rapid the more nearly the plant is out of this rest. The ending of the rest period is later with some species than with others and with some varieties of the same species than with others. The beginning of the rest period is later for young trees and trees that receive rather severe spring pruning and are well cultivated and fertilized; the ending of the rest is also later for such trees. The rest period may be broken by treating with anæsthetics and by many other special treatments. In nature it is generally broken by prolonged exposure to low temperature. It seems that a temperature a little above freezing is better than one below freezing. Deciduous plants kept in a greenhouse at a temperature favorable for growth may never grow after going into the rest, or they may grow feebly after they have become very weak.

Seeds of most deciduous fruits have a rest which is prolonged if the seed becomes very dry. This rest is best broken with many of them by exposure in a moist condition, for one to three or four months, to a temperature of 4° to 6° C. It may be broken by longer exposure to a temperature of 0° to 2° C. or 7° to 10° C.

CHAPTER 4

GROWTH, EXTENT, AND DISTRIBUTION OF THE ROOTS OF FRUIT PLANTS

THE problem of the water supply to the various parts of the tree is intricate. Livingston (473) suggests that the water supply to the growing point is determined by the water-supplying power of the soil, the absorbing power of the roots, the conducting power of the plant, and the evaporating power of the leaves. No adequate understanding can be had of the problems concerning the water supply to the fruit, if any one of these features is ignored. A discussion of problems concerning the water-supplying power of the soil does not come within the province of this book. The soil will be discussed only from the standpoint of the soil requirement of the various fruit species.

A knowledge of the nature of the root growth of the different fruit plants is of importance, not only concerning problems of the water supply, but also concerning problems in the mineral-nutrient supply. Any discussion of the nature of the root systems of the different species or of the features that influence root growth must be very inconclusive because of the great difficulty in studying growing roots.

Water is absorbed by normal roots mainly through the root hairs, which are extensions of the epidermal cells a short distance back of the growing points. It is absorbed also by the younger parts of the root that have not yet been covered with cork. Casual observation suggests that with some fruiting species root hairs are seldom formed. It seems probable that generally, with uniform water-supplying power of the soil, the absorbing power of the roots will be in proportion to the size of the root system; though a root system that is growing rapidly, and, therefore, has many growing points and many root hairs, may have a greater absorbing power than a larger root system that is growing more slowly and has fewer root hairs. The number of root hairs or the number of growing points of fruit tree roots cannot be studied in any practical way. Therefore, the size of the root system is probably the best available measure of the absorbing power of the roots.

Nature and extent of root growth. It is readily observed that trees may be grown to some degree of satisfaction in soils in which the ordinary field crops could hardly be grown. Perhaps this may be explained by the nature of the root systems. There is relatively little known about the growth habits of fruit-tree roots; but what evidence we have is to the effect that the spread and depth of the roots may be rather great. Thus Bailey (369) found a small Howell pear tree, the diameter of whose top was but seven feet, with roots extending twenty-one feet from the base. If the roots extended as far in the other direction, the total spread was forty-two feet or six times that of the top.

Goff (436) studied the root systems in a Wisconsin soil, which he describes as a clay loam overlying a subsoil of about five feet of sandy clay. In this soil, a McMahon apple tree seven years old that had made a rather poor growth showed roots which extended horizontally a little more than twelve feet and descended to a depth of nine feet. In other words, this small tree drew its water from a cylinder of soil a little more than twenty-four feet in diameter and nine feet deep. Goff suggests that this may explain the drought resistance of the apple. Thus, during the summer of 1894 and 1895 in Wisconsin many large hard maple and red oak trees were killed by the drought, but apple trees were uninjured and many bore a good crop. A Niagara grape had roots extending horizontally at least thirteen feet and downward to a depth of at least five feet, very few roots being found less than eighteen inches beneath the surface. The roots of a Gregg raspberry extended horizontally four feet and downward to a depth of five feet, while those of the strawberry made comparatively no horizontal growth, all the roots being directly beneath the plant and growing into the soil nowhere deeper than two feet.

Burrill and Blair (400) report young apple tree roots as much as five feet beneath the surface in Illinois in a soil that they do not describe in detail. Peren (498), studying trees in certain soils in England, found most of the roots within twenty inches of the surface with nearly all the trees studied, though the spread of the roots was rather great.

The above work was done in sections where there is generally a considerable summer rainfall. In arid sections where the water table is low during all the year, it would be expected that, provided there were available water at rather low levels, the roots might penetrate even more deeply than did those studied by Goff. Hilgard and Loughridge (452) found that in some of the dryer soils in California the roots show a greater tendency to go downward than they show in humid sections. Farmers digging wells are reported to have found cherry roots twenty-one feet below the surface and plum roots twenty-four feet. On the other hand, Mason (479) found that, in a section where the rainfall is so light that it does not penetrate deeply in the soil, olive roots grow mainly near the surface, but spread widely. With a tree about six feet high, having top spread of about seven feet in diameter, there were thick masses of roots extending ten to eleven feet in every direction from the trunk. The olive is reported also by Crider (980) to be a shallow rooting tree. However, I know of no studies of olive root systems in well aerated soils having available water to great depths. Ballantyne (373) studied the root growth of fruit trees in Utah. The soil was a sandy clay at the surface underlaid by almost pure sand more or less honeycombed with large clay cells. The water table was eight feet eleven inches below the surface when the trees were dug. Seven large main roots of a Kings Prize peach tree, ten years old, were traced to a depth of nine feet or lower. Most of the root system was deep in the soil. Roots of an Elberta peach tree of the same orchard, but so near the head irrigation ditch that the water supply may have been better, were not so deep. With a Winter Bartlett pear tree about eleven feet high the total spread of roots was more than twenty feet and roots were found at a depth of nine feet and three inches. Roots of a Jonathan apple tree seven years old had reached the water table at a depth of ten feet, and a single root of a Thompson Seedless grape had reached a depth of nine feet and two inches.

Ballantyne found that when the water table rose and remained at the higher level for a considerable period, the roots that were thus submerged were killed to the water level. It is not known how long these roots were submerged. If a high water table through a few weeks in spring or early summer kills all roots to the water level, the depth of rooting in some orchard sections is rather small. That the water table during early summer may determine the depth of rooting is suggested, though not proved, by experience with some six-year-old peach trees in the Cornell Experiment Station orchard. They were located on a rather steep north hillside. The soil was sandy, but that about two rods farther north was heavy clay. The water may thus have been held in the sandy soil by the dam of clay farther down the hill. In digging some trees located about thirty-two feet south of the clay, it was noticed that the lower roots were practically level in the soil, as if there had been a level surface through which they could not penetrate. Since the slope was to the north, the roots on the south side of the tree were considerably deeper than those on the north or lower side. Most of the roots on the north side were only about ten to twelve inches below the surface; though the loose sandy soil continued much deeper than that. Trees farther up the hill were also dug. It was found that with trees located about sixteen feet from the beginning of the clay, the lowest roots were only eighteen inches deep, while the larger part of the root system was about nine inches deep. With trees farthest up the hill, the lowest roots were a little more than five feet deep and the larger mass of the roots about two feet deep. The root systems of trees part-way up the slope were more shallow than those at the top, but considerably deeper than those at the base. If a high water table, by killing the lower roots, determined the depths of these root systems, it must have been that in winter, spring, or early summer; for in mid-summer the water table below all these trees was considerably lower than the roots penetrated. The trees with the shallow roots were as vigorous and healthy as those with deeper roots. It would be expected that killing of the deeper small roots each spring would cause no striking influence on the vigor of the trees. However, if the water table, after being low during several springs, should rise in one and kill the roots that had grown during the period, perceptible reduction of early summer vigor of growth should result. We shall see in the next chapter that lack of oxygen may inhibit root growth in the deeper layers of compact tenacious soils even when the roots are not killed by temporary high water tables.

While there are great differences in the nature of the root systems of different species, some having greater ability than others to penetrate deeply into a soil with very little available water at the lower levels, and some having greater ability than others to penetrate a nearly impervious layer or to survive poor soil aeration, it seems probable that, with a soil well aerated and having some available water and nitrogen to great depths, the roots of nearly all fruit trees and of some small fruit plants will penetrate to such depths.

Season of root growth. Goff (438) found in Wisconsin that root growth with many fruit plants began appreciably earlier in spring than top growth. This was true of the pear, sour cherry, red and black currant, and gooseberry, and of a number of forest species. The red currant (*Ribes sativum*) started root growth farther in advance of the opening of the buds than did any other woody plant studied. With the Worden grape root growth began later in spring than with most other fruit plants, but this was true also of the opening of the buds. The strawberry had started root growth by March 22d, earlier even than the above-named woody plants. The earliest root growth was in the surface areas of the soil and the most rapid was at the end of main roots or the larger branches.

Hammerle (440) seemed to find, with the roots of *Acer pseudoplatanus*, that there is a periodicity in root growth, growth being active early in the season and late in the season, with a mid-summer period of little growth. MacDougal (484 and 485) studied the root growth at Urbana, Illinois, of *Acer saccharinum*, *Carya laciniosa*, and *Quercus alba* during the seasons of 1914 and 1915, and of *Tilia americana* during the season of 1914 only.

He made his observations through plates of glass placed horizontally against roots near the surface and others vertically against the roots and soil about two feet beneath the surface. The glass was protected from the light and fitted tightly so that few air spaces were between it and the soil. Observations were made at intervals of seven to fifteen days from April 26th to December 7th in 1914, and from March 23d to September 2d in 1915. In 1914 root growth was observed by April 28th in *Acer*, *Tilia*, and *Carya*, and May 5th in *Quercus* (observations on *Quercus* were not made on April 28th). Growth continued until November 24th on all and until December 1st on *Acer*. During late July and all of August there was no growth except back of one plate against *Carya laciniosa* roots. This was a very dry period. During the season of 1915, when there was a better distribution of rainfall, growth was observed from April 5th or 13th throughout the season. While the time for bud opening is not given, it seems probable that for the climate of Central Illinois it would be, at least for *Carya* and *Quercus*, considerably later than April 5th or 13th.

Cranefield (414), beginning May 25th in Wisconsin, dug narrow trenches so near the plants that roots were cut. These were filled with soil, packed firmly. On July 10th, August 22d, and October 6th, this soil was dug out for examination of the ends of the roots, being replaced each time. New roots had grown out into the fresh earth at each examination. There was no growth in the tops of the trees after July 1st. While it is not impossible that the cutting of the roots would stimulate growth at a time when very little growth was otherwise taking place, this study suggests, as the others have, that there is root growth whenever the food and moisture supply is adequate and the temperature is suitable. We have seen that Curtis (92) seemed to find roots to have no rest period.

None of the above studies give much indication as to the season of greatest root growth if there is such a season. If soil conditions were favorable, if there were no rest period, one would expect root growth to be largely determined by the supply of carbohydrates or of nitrogenous material elaborated in the leaves, and to be most rapid in spring when the reserve food supply was large, and in late summer after the tree had ceased to use a large percentage of the elaborated foods in top growth. Barker (375) seemed to find this true. He studied root growth of young apple trees by suspending the roots in small barrels and arranging an automatic device by which they were sprayed with a nutrient solution every three to five minutes. The roots could thus be observed; and, due perhaps to the excellent aeration, they seemed to make a very healthy growth. There was a short period of rapid growth beginning a little in advance of shoot growth and continuing for a short time after shoot growth began. During the remainder of the period of rather rapid shoot growth, June and a part of July, root growth was slight, after which time it became rather rapid and continued until late autumn; most of the season's root growth being made in this period after shoot growth had ceased.

Relative size of root system and top. It is of interest to know how large the root system is in proportion to the top. It is evident that this relation will be influenced by the supply of water and mineral nutrients. It should be influenced also by the length of the growing season. Since top growth is made during a small part of the growing season, while root growth continues throughout that season, we expect the relative size of the roots to be smaller where the growing season is short. Pickering (681, 16: 52) gives relative weight of root and top for a rather large number of apple trees and a considerable number of plum and pear trees, ten to twenty years old. The average percentage of the whole tree weight that the roots constituted was, for the apples 22.9 per cent, for the pears 23.5 per cent, for Damson plums 25.2 per cent, and for other plums 28.3 per cent. The Bramley apple has but a very small percentage of root weight and it is this one variety that reduces the average for the apple. With many of these trees the small roots were not all dug. On the other hand, the soil was not washed off. Pickering thinks the percentages are somewhat low. Any one who has dug up roots, however, knows that the very small roots are exceedingly light, so the percentages may not be far too low. Pickering thinks we can be reasonably certain that a percentage of 25 to 30 is high enough.

At the Cornell Experiment Station some evidence was found that the roots constitute a smaller percentage of the total weight of young nursery trees than of trees a little older. Thus, with thirteen Delicious apple trees in the nursery two years the roots constituted 12.6 per cent of the total weight of the trees; while with the same variety, with forty-one trees left in the nursery a year longer, the roots constituted 23.3 per cent of the total weight of the trees, and with Northern Spy trees in the same nursery, but left two years longer, the roots constituted 30.3 per cent of the total weight of the trees. It is doubtful, however, if those differences are due to age alone. The summer of 1917, at the end of which the first trees were dug, was about a month shorter than normal and the rainfall was large and well distributed. These conditions resulted in an excellent top growth. It seems probable that carbohydrates or some other materials elaborated in the leaves were, therefore, used in top growth to a greater extent, and less were available for the roots. The two following years were rather dry and the trees were becoming large enough more nearly to exhaust the water supply of the soil; and so shoot growth ceased rather early in both years. Therefore, throughout the growing season there must have been a relatively larger carbohydrate supply for the roots. Other young trees in the orchard of the Cornell Experiment Station made an exceptional shoot growth during the summer of 1917, but made a growth much below normal early in the summer of 1918. It seems probable that on account of conditions favoring a very large top growth during the summer of 1917 the carbohydrate supply was used for top growth at the expense of the roots (though more roots than are usually killed may have been killed by the high water table early in 1918). When the buds on the abnormally increased top opened in spring, the leaf surface was so great that the root system which had not been increased proportionately could not supply water as fast as it was lost. Growth, therefore, stopped as it would during a drought. After growth had ceased, however, there would soon be an accumulation of carbohydrates and probably an acceleration of root growth; and, unless the rest period began in time to prevent it, there should have been a second growth caused by the additional water supply resulting from the increased root system. As a matter of fact, nearly all young trees in the Cornell Experiment Station orchard that showed this early cessation of growth started a second growth beginning about June 15th to July 1st after practically all terminal buds had been formed.

The records of Pickering in England as to relative weight of root and top and those at Cornell University were with trees growing in rather humid climates where the growing seasons were relatively short. In less humid sections with longer growing seasons, where, except under irrigation, shoot growth would continue through a smaller part of the growing season, the relative size of the root system would probably be larger.

It is well known that the nature of the soil has much to do with the relative size of root and top. Thus, in a heavy clay soil with an abundant water and nutrient supply, the root systems, with nursery trees, at least, are relatively small. This would be expected, since conditions are favorable for the use of elaborated foods for top growth. The root systems in the gravelly or sandy soils may be larger also on account of the better aeration.

Effect of cultural methods on root growth. Bailey (369) found the root systems of trees in cultivated soil deeper than those of trees in sod, and not so long and straggling in growth. Burrill and Blair (400) and Hedrick (623) seem to have found the same. On the other hand, Green and Ballou (614a) seemed to find as many tree roots rather deep in the soil of the sod mulch plats as in the cultivated plats, though there was also a great accumulation of roots just beneath the mulch. The work is not conclusive, however, since they used only blocks of soil one foot square and one foot deep.

Woodbury, Noyes, and Oskamp (736) did not find any apparent influence of cultural methods on the depth of root growth during the first four years in the orchard. With these young trees the depth of planting and the root growth in the nursery had more to do with the depth of rooting in the orchard than had cultural methods. Cultural methods influenced the nature of the root system, however. Thus, trees under grass had a larger percentage of their root systems composed of fibrous roots, and had larger root systems in proportion to their size than had trees under cultivation or heavy mulch.

In a soil of such nature that the roots tend to grow near the surface, one might expect them to grow more deeply under cultivation. For it seems probable that, soil type and drainage being equal, the amount of root growth will generally be determined by the elaborated food supply that makes its way to the roots from the leaves. And if the shallow roots be cut by the plough, then the number of growing points will be reduced, and more food should be available for the deeper roots. Further, the better aeration in a cultivated soil should accelerate root growth in the lower levels.

In Table 7 it was suggested that treatments, such as dormant pruning or supplying abundant nitrogen that encourage prolonged shoot growth, either reduce root growth or do not increase it proportionally as much as top growth is increased. The proportions of root dry weight to top dry weight was reduced by such treatments. This would be expected if the most rapid root growth should tend to come after shoot growth had ceased or declined. Turner (717) found with barley and corn that greater growth of tops relative to roots was made by the plants having the most abundant nitrogen supply; abundance of nitrogen did not increase root growth as much as it increased top growth. In humid climates, cultivation seems to influence growth largely through its influence on the soil nitrogen supply. And Lyon, Heinicke, and Wilson (664) found the root weight relative to top weight larger with apple trees in timothy sod than with cultivated trees and larger with unfertilized sod trees than with sod trees receiving large applications of nitrogen. Cultivation and the application of nitrogen greatly increased root growth, but not relatively as much as they increased top growth. Cullinan (418) found the roots to constitute 23.7 per cent of cultivated apple trees, 26.1 per cent of mulched trees, and 31.6 per cent of trees in sod. Cultivation or mulching greatly increased root growth, but not as much as it increased top growth. With the peach trees in Table 7, of the dry weight of wood produced by a given leaf area, 23.7 per cent was in the roots with trees fertilized with sodium nitrate, and 30.1 per cent with unfertilized trees. With the healthy Montmorency cherry trees the percentage was 27.8 for trees fertilized with sodium nitrate and 36.1 per cent for unfertilized trees. Fertilizing with nitrogen increased root growth, but not relatively as much as it increased top growth. Pruning prolongs top growth, but it also removes part of the top. Pickering (681, p. 57) found a slightly greater size of roots relative to the tops with trees receiving much pruning than with unpruned trees. In the experiments at Cornell University (782), this was generally true; but with Early Richmond cherries the root system of the pruned trees was smaller relative to the top than with unpruned trees. Of course, in all cases, when the weight of the pruning was considered, it was found that pruning had reduced the growth of the roots much more than it had reduced the growth of the top. Thus, application of nitrogen increases root growth relatively less than it increases top growth, while dormant pruning reduces root growth relatively more than it reduces top growth, in both cases probably because shoot growth is prolonged and materials are used for such growth in the top instead of accumulating and moving to the roots.

Summary. The root systems of most fruit plants are rather large and seem to extend into the soil as deeply as continuous aeration makes possible. It seems probable that in humid sections the water table during spring and early summer tends to determine the depth to which the roots are found, and that a high water table after several seasons of low water table may, by killing the considerable portion of the root system that is in the free water, cause an appreciable reduction in growth or in the size of the fruit in some years. In arid sections lack of water in the lower levels may limit the depth of root penetration. The roots seem to have no rest period, but to grow whenever moisture and temperature conditions are favorable and a food supply is available. The size of the root system in proportion to the top is generally greater when soil, climatic conditions, or cultural features are such that shoot growth ceases rather early in summer, so that there is an accumulation of food materials and a relatively more rapid movement to the roots.

CHAPTER 5

SOILS FOR FRUIT TREES

THE nature of the soil as to aeration, drainage, retentiveness, and physical characteristics is of peculiar importance with fruit trees. With many annual crops the soil may be used only during that part of the year when moisture conditions are favorable. Thus, a crop of wheat may be harvested before the time in summer when in some sections the soil is liable to be too dry for crop growth, or some other crop may be sown after a soil that is very wet early in the season has reached such a condition that it can be worked. With trees, however, the roots must endure whatever conditions prevail in the soil throughout unfavorable as well as favorable years. This suggests that a fruit soil should be one in which the fluctuations in moisture supply are very small. Yet it is true that few crops are adapted to as wide a range of soils as some of the fruits, particularly the apple. Thus, we find fruits growing well in rather heavy clay soils and in the exceedingly light dry gravelly soils, where few grain crops can be grown with profit. The explanation may be in the deep rooting habit of trees. Thus, a very deep gravelly soil, even though the moisture in the surface layers where most annual crops would feed is entirely inadequate, may furnish a larger and more continuous water supply to the deep rooting fruit trees than will a soil that is very productive for annual crops, but that has the water table or a rather impervious soil layer near the surface to prevent deep root growth.

In a heavy clay soil the root system is much smaller than in a well-aerated sandy or gravelly soil in which the surface moisture supply is inadequate. At least, this is markedly true of nursery trees. Thus, with nursery trees in my experience the root systems were much larger in proportion to the top when grown in light gravelly soils of the Ozark region than when grown in a very retentive heavy clay soil in central Missouri. This may be largely because of the good aeration of the lighter soils. Thus, Curtis (92) thinks that oxidation is an important factor in the formation and growth of roots on cuttings. When he stimulated root growth by treating cuttings with potassium permanganate, the stimulation, he thinks, was due to increased oxidation. Nurserymen try to find especially well-aerated soils in order to obtain good root systems.

Hutchins and Livingston (463) have suggested a method of measuring the oxygen-supplying power of the soil by use of which they seemed to find that the supplying power of a packed wet soil may be no more than one per cent of the amount of oxygen that the same soil freshly cultivated and without excessive moisture may supply. The oxygen-supplying power was found to vary inversely with the depth in soil with its wetness, and with its compactness. Clements (408) has reviewed much literature showing that not only does the supply of available oxygen decrease with the depth of the soil and with the amount of water in it, but that the amount of carbon dioxide increases; and that in compact wet soils rich in organic matter injury to the roots from lack of oxygen seems to be more frequent than is commonly supposed; also that some of the toxic conditions occasionally found in soils seem to result from high carbon dioxide content and the products of anaerobic respiration. In the lower levels of rather compact wet soils even above the water table, such conditions may often inhibit root growth.

It is, perhaps, on account of the great penetration of the roots and the resulting increased water supply that trees in a rather poor gravelly soil may, if supplied with nitrogen, make a very much more rapid growth during the first few years in the orchard than trees in a heavy clay soil. Later, however, when the roots seem to be exhausting the water-supplying capacity of the gravelly soil, those in the clay soil may grow the more rapidly. This is particularly true of peach trees. The deep rooting habit of fruit trees, then, gives them the benefit of having a water supply less influenced by fluctuations in rainfall. From the standpoint of vegetative growth it seems that the most desirable soil is one that is retentive of moisture, but has the water table rather deep, and is so well aerated that the roots may penetrate deeply.

Soil drainage. While in some climates apple and pear trees may do fairly well in soils too wet in the spring for the best development of some field crops, good drainage is generally more important with trees than with annual crops. An injuriously high water table once in ten years would destroy only the one crop with annuals; while it might destroy trees that had been developing ten years.

The injury to the roots from a high water table is due, at least in large part if not entirely, to the exclusion of oxygen; and the duration of such a high water table required to injure the roots submerged seems to depend upon the condition of the roots. If they are growing and respiring rapidly, a short period under water may kill them. On the other hand, in sections with cold winters water may stand on the surface of unfrozen soil for considerable periods during winter thaws or in early spring without apparent injury to the roots. Coville (412) says that at Wareham, Massachusetts, there are swamp blueberries, the roots of which have been under three feet of water from December to May for twenty years without apparent injury; though when the roots are growing excessive watering is injurious.

In some soils in California there is sometimes killing of the roots by water, though all the rain is in the fall, winter, and spring, the soil being excessively wet only in winter and spring. In the spring of 1923 there was a considerable amount of such injury, but the rainfall was exceptionally heavy late in the spring and the water table was near the surface later in the season than usual. As to whether or not, in such mild climates, roots remain throughout the winter in a condition such that they are more susceptible to injury by a high water table than are the roots during winter thaws and in spring in sections where the winters are colder, I know of no data. It may be that there is such injury only in years when the rainfall, rather late in spring, is heavier than usual. On the other hand, it may be that an early autumn rain that starts the roots into growth while the soil is warm may cause them to be more susceptible to injury by a high water table even in mid-winter. Whatever may be the truth as to these questions, it is certain that in such sections, with considerable winter and spring rainfall and with winters during which the soil is unfrozen, good soil drainage is as important as with similar soils in sections with greater rainfall, but with the soil frozen during much of the winter. In fact, it may be more important.

In sections where the water table at times is injuriously high, good tile drainage may save the life of the trees in exceptional years; and by making possible a deeper root development, thus making available to the tree the moisture and nutrients of a greater area of soil, it may increase the bearing capacity of the tree in all years. This latter benefit may be of more importance in a section where the rainfall is all in winter and spring than where there is nearly adequate summer rainfall. Some soils may be so tenacious and resistant to percolation that tile drainage is not effective enough to be profitable. If one should attempt to grow trees in such soils, one might improve conditions to some extent by having the trees on considerable ridges, provided there were outlets for the water between the rows. A winter growing cover-crop to remove water by transpiration might often be beneficial in such soils.

Where irrigation is practiced, drainage may be necessary in the low places not only to prevent injuriously high water tables, but in many cases also to prevent the development of alkali.

Requirements of different fruits. It is sometimes said that certain fruits, such as the blackberry and the gooseberry, require a cool soil, a sandy or gravelly soil being too warm.

Table 10

Showing the Monthly Maximum, Minimum, and Average Temperatures in Degrees Fahrenheit at Two, Four, and Six Inches below the Surface of Different Soil Types

Month		Gravel			Sand			Loam			Clay		
		2″	4″	6″	2″	4″	6″	2″	4″	6″	2″	4″	6″
June............	Max.	77.73	73.87	71.27	78.25	75.40	73.10	74.40	71.25	66.82	73.86	70.19	67.73
	Min.	57.61	57.90	59.84	56.73	57.35	59.01	57.07	59.93	60.72	57.82	58.78	60.88
	Avg.	69.78	67.92	66.79	69.98	68.55	67.22	67.86	66.42	63.79	67.84	66.46	64.45
July............	Max.	83.29	80.19	77.41	84.41	81.91	79.45	79.80	77.50	73.27	80.54	76.36	74.47
	Min.	63.88	64.84	66.18	63.34	64.07	65.56	62.73	66.42	66.91	65.03	64.86	67.28
	Avg.	75.70	74.18	72.70	76.18	74.96	73.69	73.41	72.82	70.12	74.39	71.55	71.04
August.........	Max.	76.90	74.07	72.42	78.01	75.48	73.94	73.57	71.84	68.75	74.32	72.00	70.14
	Min.	60.42	61.76	63.61	69.41	60.65	62.75	59.79	63.12	64.03	60.95	62.84	64.63
	Avg.	70.50	69.45	68.58	70.80	70.00	69.26	68.54	68.06	66.28	69.44	68.17	67.38

The work of Bouyoucos (392) would lead one to think that, at least in humid sections at latitudes as high as 40°, the differences in temperature among the different soil types are not great. Table 10 gives a summary of the maximum, minimum, and average soil temperatures for the months of June, July, and August, 1915.

The differences in temperature for the different soil types are not very great, and even these differences prevail during only a very small part of the day. In a fruit planting the differences in maximum temperature between sandy or gravelly soils and clay or loam would probably be less than those recorded by Bouyoucos, for the soil in the planting would be shaded during portions of the day. Since the maximum soil temperature is lower than the air temperature, the protection from the wind furnished by the trees or other plants will further reduce the range of soil temperature. It would seem, then, that under field conditions differences in temperature of the different soil types could hardly be of great importance in determining their desirability for any fruit crop. This view is in agreement with the results of Oskamp (679) with apples. Thus, with plats receiving four different soil treatments the best tree growth was obtained on the cultivated plats which showed the highest summer temperature and on mulch plats which showed the lowest.

The following summary statement of soil requirements of the different fruits is made from the articles on the various fruits in Bailey's *Standard Cyclopedia of Horticulture:*

Almond: Light, well-drained soils. More tolerant of drought than other deciduous fruits.
Apple: A soil that will grow good crops of wheat or corn.
Apricot: Deep, dry, loamy, or gravelly. Tolerant to heavy, moist soils.
Blackberry: Deep, mellow clay loam with a good supply of humus. (Gravelly or sandy soil too hot.)
Blueberry: Best in an acid soil composed of a mixture of pure sand and peat. Good aeration is desirable.
Cherry (*sweet*): Comparatively light, sandy or gravelly, or even stony loam.
Cherry (*sour*): Best on somewhat heavier soil than that for sweet cherries.
Currant: Best on rich, well-drained clay loam.
Dewberry: It does best on a lighter soil than that which is best for the blackberry.
Gooseberry: Well-drained, heavy clay loam. Soil should be cool.
Grape: Satisfactory in all types, but loams and clays preferred if drainage is good.
Peach: Adapted to a wide range, but does best in a sandy or gravelly or stony loam, deep and well drained. It does not do well on poorly drained soils.
Pear: Does well in a variety of soils, but best in a strong loam of moderate depth overlying a porous subsoil. Some varieties do well in a sandy soil, but such is generally to be avoided.
Plum (*Prunus domestica*): Best in clay loams such as are suited to pears; yet many varieties thrive on light or even sandy soil.

Quince: Does best on a deep rich warm soil that is well drained.

Raspberry: Deep fertile loam with plenty of humus. Most varieties thrive the better on the heavier, rather than on the lighter, types of soil.

Strawberry: Rich, rather moist, sandy or gravelly loam.

In so far as the healthy development of the plant is concerned, these statements as to soil requirements must not be given too much weight. They certainly cannot be taken as indicating that the fruits differ greatly as to the kind of soil in which the plants reach their best development in growth and in setting of fruit buds. In fact, as we have suggested, in so far as the plants are concerned, the ideal soil for all fruits seems to be one that is reasonably rich, well drained, and well aerated so the roots may penetrate deeply, and one in which the supply of moisture is adequate for the tree. The most nearly ideal soil in this regard that I have seen is the loess to be found along the Missouri and Mississippi Rivers. It is of rather uniform composition to great depths and is always well drained and well aerated. Because of its aeration, the surface area is somewhat dry and the humus and nitrogen are depleted rather rapidly, and so it is not generally considered a corn soil unless manure is used. From a rather large amount of observation I should say that every kind of fruit that has been tried extensively does better in that soil than in any other to be found under similar climatic conditions. This seemed true even of blackberries, gooseberries, and quinces, the fruits that are supposed to prefer a soil that is cool and retentive of moisture near the surface.

Fruit species vary as to their tolerance of soils not so well aerated as an ideal one, like the loess, and of soils less retentive of moisture than the ideal one. There are among plants generally great differences in tolerance to poor soil aeration. Thus, Cannon and Free (404) found some plants but slightly injured or not injured at all (*Salix*) by exclusion of oxygen from the roots, while others (*Opuntia*) showed marked injury. They think that the distribution of plants, at least those of arid regions, is influenced greatly by their relative need for good soil aeration. With fruits, when soils are too clayey or wet for the best results, the apple, pear, and plum will be injured less than the peach or cherry (sweet or sour). The trees of the sweet cherry, almond, apple, and peach seem to be injured less than most of the others by having the soil too gravelly or sandy.

While the above seems true in so far as the growth and productiveness of the tree are concerned, the nature of the soil may greatly affect the quality and size of the fruit. With the peach a sandy, gravelly, or other light soil is generally desirable in so far as quality is concerned. Thus, at Columbia, Missouri, the quality as well as size of peaches from trees grown in the heavy clay soil was much below that of fruit from trees grown in loess soils but five or six miles away. The same was true of the Jonathan apple. On the other hand, the fruit from pear trees, unless it be the Kieffer, growing in a rather heavy soil is generally considered better than that from trees in light soil. The same is true of some varieties of apples. With pears the grit cells seem more numerous when the soil is light. Fruit trees cease growth earlier and the fruit also ripens earlier on the light soil.

Soil for varieties of apples, pears, and peaches. Wilder (544 and 545) has studied the soil adaptations of some apple, pear, and peach varieties. The following is a summary of his conclusions as to the soils on which apples of the best quality are grown:

Baldwin: Medium to semi-light when clay is considered heavy and sand light.
Rhode Island Greening: A surface soil of heavy silty loam or light silty clay loam underlain by silty clay loam.
Hubbardston: Lighter soil than that for the Baldwin. A rich fine sandy loam.
Northern Spy: A soil like that for the Rhode Island Greening gives fruit of the best texture, but the color is poor and the skin greasy. A lighter soil, but no lighter than a heavy fine sandy loam underlain by a light clay loam should be used.
McIntosh: In Massachusetts, a rather heavy Baldwin soil.
Tompkins King: A light Rhode Island Greening soil. (At least one where the water supply is so good that a tree will not suffer a check on approach of drought.)
Rome: Baldwin soil.
Grimes: Rhode Island Greening soil.
Jonathan: Light loamy.

With the exception of Tompkins King, this classification is largely with reference to the quality of the fruit only. There is little to indicate that the yield is better on the particular soils mentioned. Thus, the Baldwin soil is one in which maturity will not be too early for best quality and keeping and too late for color or best quality. A heavy soil gives a green Rhode Island Greening. If a market does not prefer fruit of this variety grass-green, there seems to be no reason why the trees should not be planted on any good soil; but, since high color is not necessary, it may well be grown in a soil too heavy for best color and quality in Baldwin. Hubbardston yields well in a heavy soil, but the color is not good and the skin of the fruits from such soils becomes greasy in storage, while fruit of good quality is obtained when the soil is light or gravelly. With all of these varieties it is probable that the largest yields would be obtained from trees in a soil in which they make the best growth; a soil well aerated so deeply that the roots may penetrate to where there is very little annual fluctuation in moisture supply, and one containing enough clay or other fine material to make it rather retentive of moisture. The mineral nutrient requirements of the different fruits will be discussed later.

Wilder says that in the Hudson River section of New York the best results with Kieffer pears are on sandy, porous soils; that Bartlett and Seckel thrive on a richer soil than the Kieffer, and that Bosc does best in a friable loam. Experience in New York suggests that in that section Seckel and Kieffer are not as tolerant of heavy, clayey soils as Bartlett and many other varieties. Seckel pears of the best size and quality seem to be obtained from trees growing in a well-drained, shaly, gravelly, or sandy loam.

While peach trees generally tend to bear better fruit when grown in a rather open gravelly, sandy, or loamy soil, Wilder found in Connecticut that a heavy, rather clayey, retentive soil did not seem to be as detrimental to the appearance of white peaches as to that of yellow peaches. Champion peaches, however, seemed to go down with brown rot more rapidly when grown on such soils than when grown on less retentive soils.

Summary. While it seems that with all fruit species the best growth is made, and probably the most fruit is borne, by plants grown in a soil retentive of water and mineral nutrients in which roots may penetrate to great depths without danger of being killed by a high water table, trees of some species, such as the apple, pear, and plum, will withstand wet soils better than others and some, such as the sweet cherry, almond, apple, and peach, seem to be injured less than others by the soil's being too gravelly or sandy.

The quality of fruit is influenced by the nature of the soil; most pears being of better quality when the trees are grown in a medium heavy loam and most peaches when they are grown in rather light soil. Some varieties of apples, such as Hubbardston and Jonathan, are of better quality when the trees are grown in a light soil; and probably nearly all are of better quality if the soil is no heavier than that described as an ideal fruit soil.

CHAPTER 6

VEGETATIVE PROPAGATION OF FRUIT TREES

WITH very few fruits are the plants grown as seedlings. In order that the grower may be certain as to the kind of plant he will obtain, all fruits are propagated vegetatively except a very few with which vegetative propagation is extremely difficult and expensive. The latter class includes no temperate zone fruit. It is not the purpose here to discuss all the problems of the nurseryman in growing fruit trees, but only some of his problems in getting good root systems.

Propagation on own roots. The simpler forms of propagation are those by which the plant is on its own roots, such as layers including tip-layers, stolons, root cuttings, and branch cuttings. Relatively, few of our tree fruits, such as the Angers quince and Marianna plum, are propagated easily in any of these ways. Some varieties of apple can be caused to root by mound or stool layering; that is, cutting the stem back nearly to the ground and banking earth over it. Roots form at the base of the new shoots that grow from around this covered stump. These, with their roots, are broken off from the stump and planted. Paradise and Doucin apple stocks are obtained in this way. Barker and Spinks (377) and Hatton (445) found seedlings of the ordinary cider apples ("crabs"), and Hatton (445a) found strains of the sweet cherry that could be so propagated. Strains of sour cherries and of plums are sometimes propagated by means of suckers from the roots.

Shaw (515) obtained a good stand, but slow growth in the first year, in the nursery when he propagated apple trees by means of root cuttings. Barker and Spinks and Hatton were able to propagate strains of apple stocks in this way. Yerkes (547) seems to have had good success in growing from root cuttings strains of apples used as stocks, other species of *Pyrus* and species of *Prunus*. He found much better results with roots one year old than with older ones. Roots three sixteenths to one half inch in diameter seemed the best. Pieces about two to two and one half inches long were used. Plants from such root cuttings were a little larger by the end of the first summer than were plants of the same kinds grown from seed.

Curtis (92) has tried a number of chemicals as stimulants to root growth on cuttings. Potassium permanganate rather markedly stimulated the formation of roots with *Ligustrum ovalifolium* and several other species, including one of *Prunus* (probably the Myrobalan plum). Manganese dioxide, manganese sulphate, and boric acid also stimulated root growth to some extent. However, these species generally root readily from cuttings; and there is no evidence as to the possibility of making use of some such stimulant in propagating species which generally do not root satisfactorily from cuttings. Curtis thinks that the stimulation to root growth by potassium permanganate is due to its catalytically accelerating oxidation. The stimulation by some of the others may possibly be explained in the same way. He thinks that the practice of burying cuttings with the bases upward and the use of bottom heat may be explained as methods of increasing oxidation in the rooting parts. Bottom heat may also tend to make the temperature more favorable for root growth than for top growth and thus to reduce the tendency for the supply of plant foods to be depleted in top growth.

With tomato and tradescantia cuttings, Starring (522) found much better rooting when the carbohydrate content of the tissue was high than when it was low; and, with carbohydrates high, rooting was somewhat better when the nitrogen content was low than when it was high. It is generally considered better to make dormant cuttings early in winter soon after leaf fall, and to store them in a cool, dark place. Curtis thinks that the benefit from this practice may be due to the fact that, apparently, there is no rest period for root growth, and when the cuttings are taken while the tree is in its rest, incipient root development may take place while no plant food is being used for top growth. The cuttings should then more quickly establish root systems in spring after planting.

While most fruit trees cannot generally be propagated from twig cuttings and cannot be grown cheaply enough by mound layering or from root cuttings, with the apple, and perhaps with some varieties of pears, trees on their own roots may be obtained indirectly. Whip grafts can be made with very short piece roots and long scions. These are planted so deep that only about one bud is left aboveground. After the tree has grown a year, it is dug up, and, if scion roots have formed, the original root or stock part is removed and the tree is reset. This, of course, makes it take a year or two longer to obtain a tree of good planting size. Shaw has made use of this method at the Massachusetts Experiment Station in starting some very interesting studies concerning stocks for apple trees. It may be that after trees on their own roots have been obtained in this way, the best plan would be to use them to supply scion roots for propagation of other trees by means of root cuttings.

We have seen that McCallam (861) seemed to find, with the bean, that roots at the base of a stem inhibited root formation above. In my experience with some apple varieties, if, in making a graft, a piece of the scion is left projecting an inch or more below the union with the stock, root development on that part is much more rapid than is root development on the scion above the stock.

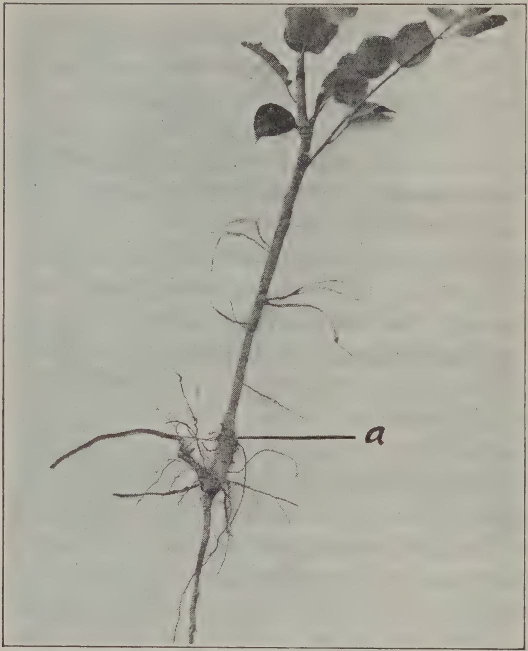

FIGURE 15. Scion roots above *a*. Development of scion roots is inhibited by the stock roots at the base (below *a*).

Graftage. The term "graftage" is here used to include propagation both by budding and by grafting. With the nurseries in the northeastern portion of the United States nearly all fruit trees are propagated by budding, with most kinds, on seedlings grown in France or America and planted in the nursery during the spring to be budded in late summer. With the peach, seeds rather than young seedlings are planted in the nursery.

Whether budding or grafting is practiced, the nature of the union seems to be approximately the same. The tissue of the stock and scion remain distinct except for a sort of interprojecting or dovetailing of the long cells, and fibers, at approximately the level at which the bud or graft was set (Waugh, 532). Most of the species with which budding and grafting are practiced are of the class mentioned by Bailey (34), with which part of the cambium cells are rather long, as shown in Figure 5, and divide nearly transversely to form the new cambium cells which elongate and crowd past each other. If cambium cells of the stock and scion should be thus dovetailed with each other, the stock and scion xylem elements from these cells, it seems, might show more such dovetailing than with species with which new cambium cells are formed by longitudinal division, though there is a dovetailing from elongation of the fibers, with the latter class of species. The relation of the type of cambial division to the graft union, it seems, should be a promising study.

According to Waugh, if the union is weak, it is generally because there is deposited, in the area of demarcation between the stock and scion, masses of loose scar tissue. This condition, he seemed to find, results from incompatibility of stock and scion rather than from faulty work in budding or grafting.

The relation of stock and scion. The interrelation of stock and scion is a question of considerable practical importance. It is a common observation that where the stock is of a species or variety whose vigor of growth is markedly greater than that of the variety to which the scion belongs, the stock at the union may be larger than the scion. The scion, however, will generally be invigorated by the vigorous stock. When the scion is from the more vigorous form, the scion part of the trunk may be larger than the stock part; though such uneven sizes of stock and scion do not always seem to be associated with differences in inherent vigor. When the scion is of the more vigorously growing form, the carbohydrate supply for the roots should be greater. In other words, the growth of the stock should be influenced by the scion. Shaw (515) seemed to find that the stock is so influenced; and also that the nature and distribution of the roots are influenced, at least while the trees are in the nursery, by the nature of the scion. During extensive observations among the nurseries at Dansville, New York, at digging time he found many examples of relationship in form between stock and scion; the French seedling roots being influenced in their branching habits by the branching habits of the scions. Since, as Knowlton (649), Auchter (30), and others have seemed to find, certain roots supply and are supplied by certain branches, it might be expected that the branching habit of the top would influence that of the roots, at least to some extent. If, in the orchard, trees of the different varieties were trained to the same number and distribution of branches, the varietal characteristics of the root systems might disappear.

Much has been written, particularly by Daniel (419–423) concerning the effect of the stock on the nature of the scion. Some of his observations are upon such characters as shape of fruit, or size and form of leaf, or upon chlorosis in leaves. Thus, he seemed to find egg plants grafted on tomatoes to bear fruit somewhat oblate like the tomato, and a pear tree worked on the quince to bear leaves intermediate between those of the quince and those of standard trees of the same variety as the scion. However, these characters are so variable that we should hesitate to reach conclusions from them alone. Leaves vary in both form and size as a result of differences in vigor of the branches. Of more interest is his description of a medlar tree, grafted on hawthorn, which bore some fruits like the medlar and some like the hawthorn. He observed a similar behavior with a peach tree on almond roots.

Winkler (545a), by use of tomatoes grafted on the nightshade and nightshade on the tomato, has explained how such a relation between stock and scion may exist. After the scion had united with the stock, he would cut it off near the union, being careful to cut through tissue of both stock and scion. In a few cases out of many trials an adventitious bud would be formed that was composed of both tomato and nightshade tissue. One of these bore fruit like the nightshade, and the seed from it produced nightshade plants. This plant, which could be propagated vegetatively, was found by study to consist of nightshade tissue covered with a single layer of tomato epidermal cells. Another plant was composed of tomato tissue covered by two layers of nightshade tissue. This also bore nightshade fruit. Another was composed of nightshade tissue surrounded by two layers of tomato cells. It bore tomato-like fruit and the seeds produced tomato plants. Such plants, with mixed tissue of the stock and scion, are often called "graft hybrids." The evidence indicates, however, that with plants produced in this way nuclear fusion has not occurred. The tissue of the two forms seems to remain distinct, however greatly it is intermingled.

Not all plants with mixed tissue originate as graft hybrids. It seems that if a mutant branch should grow from a parent branch, an adventitious bud at its base might contain tissue derived from both the mutant and the parent branch, or, perhaps more commonly, the chimera might arise directly from the mutation of part of the bud or shoot tissue. Plants with tissues of two species or varieties intermingled are called "chimeras." Where the tissue of one surrounds that of another, as in the above, it is called a "periclinal chimera." Where the tissue of the two kinds meet, but remain in sectors, neither kind surrounding the other, they are called "sectorial chimeras." The tissue of the two forms may be greatly intermingled, such a plant being called a "hyper-chimera." It seems that the medlar-hawthorn and the peach-almond "graft hybrids" are, in reality, chimeras of one or another of these types. There are on record a number of cases besides those mentioned above. The tissue of the stock is merely extended up into or around that of the scion. Water, mineral nutrients, and carbohydrates may pass from the tissue of one to that of the other. No doubt the tissue of one may dwarf or stimulate the other by its weak or vigorous growth. But there seems to be no convincing evidence of a relation other than nutritional or physical.

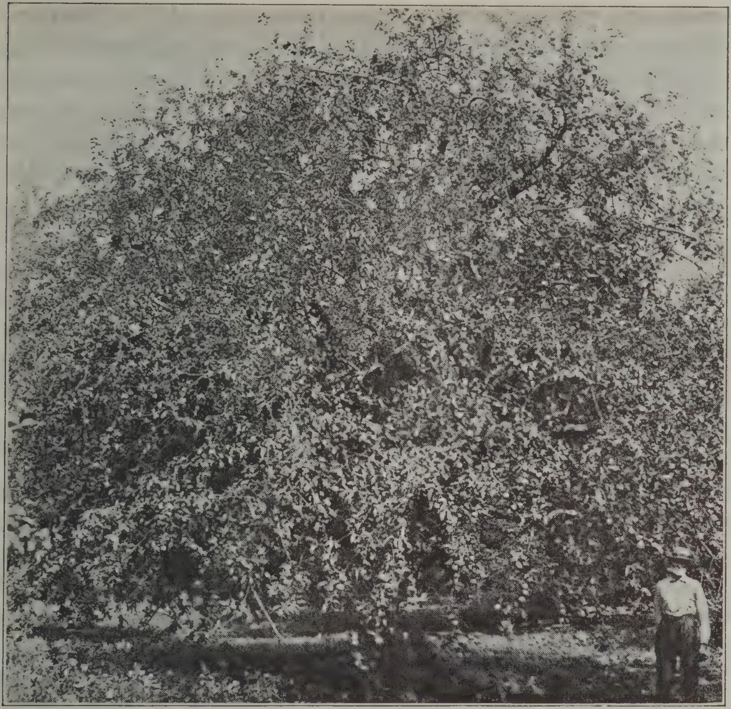

FIGURE 16. An apple tree, chimera, belonging to T. D. Whitney, of Phelps, New York. Red apples, Tompkins King, and distinctly russet apples are borne by different small branches of each main and secondary branch. Sometimes there are sharply defined red and russet sections of one apple.

Guignard (438a) has furnished evidence that some organic compounds, such as glucosides, will not move from a stock into scion or the reverse; however, Meyer and Schmidt (487) seem to find that nicotine will. Every one who has had experience with top-worked trees knows that tissues of stock and scion retain their typical characteristics. Thus, Tompkins King apple wood is less resistant to low temperature than is that of Tolman. When the former is top-worked on to the latter, the Tompkins King wood may be killed while the tissue of the Tolman remains uninjured. Except for chimeras with which, due to the intermingling, the tissue of one might physically inhibit the growth of the other, there is little experimental evidence indicating any influence of stock on scion other than an increase or decrease of water and mineral nutrient supply as determined by the growth habits of the stock. The following summary by Hedrick (446) may be accepted as representing approximately the views that have been reached by observers and workers as a result of experience; *first*, the stock modifies the form and stature of a plant; *second*, the adaptability of a species or a variety to a soil may be changed by the stock; *third*, through the stock a plant may be made to endure an incompatible climate; *fourth*, the stock, if diseased, may impart the disease to the scion; *fifth*, the productiveness of the tree is often increased by the stock; *sixth*, the time of maturity of both wood and crop may be changed somewhat by the stock; *seventh*, the color of a fruit may be altered by the stock; *eighth*, the size of a fruit is often increased by the stock; *ninth*, the stock affects the flavor of the fruit borne on the scion; *tenth*, some stocks shorten the life of the trees of which they are a part. Hatton (445b) stresses these influences and also the differences in stocks as to the strength of their hold in the soil. The second of the influences listed by Hedrick concerns the ability of different stocks to withstand unfavorable soil conditions; and, if plum roots, let us say, are more resistant to wet soils than peach roots, then it is to be expected that peaches on plum roots may be grown on wetter soils than when on their own roots. The tenth effect would be expected if the stock were of a weak kind or even incompatible for the scion. All of the other effects might result from the varying ability of different stocks to supply water or mineral nutrients to the top. Thus, with a weak stock the water and nutrient supply would be reduced, and maturity would tend to be earlier. This may affect the quality of the fruit just as early maturity caused by the tree's growing in a light dry soil may affect quality. The amount of red color in the fruit may be increased by early maturity. The fruit may be smaller than normal because of the smaller amount of water supplied by a slowly growing stock, or larger than normal because the organic food supply is rendered larger by the restriction at the union of stock and scion; just as ringing grape shoots may increase the size of the fruit.

Compatibility of stock and scion. This subject has had little careful study. It is known from experience that only botanically related species can be successfully grafted or budded on to each other. On the other hand, nearness of relation does not alone determine the degree of compatibility of stock and scion. Hedrick (446) has emphasized the fact that the pear will not grow well on the apple or the apple on the pear, though they seem closely related, yet the pear will grow readily on the quince. Sweet and sour cherries will grow well on *Prunus Mahaleb;* but *Prunus Mahaleb*, it is said, will not grow on either the sweet or the sour cherry. Something more than kinship is required for a good union, and so far we have no means of determining in advance of experience what stocks and scions will be compatible.

Dwarfing fruit trees. While the vigor of the stock may be increased by a vigorous scion, the amount of such increase is limited; a weak stock may greatly dwarf a tree, and may thus cause it to bear younger than it otherwise would. Naturally, many more of dwarf trees than of standard trees will be planted on an acre. Trees to be used for training against walls or for training in other ways with which severe pruning is practiced are generally on dwarfing stock. It seems that one can be more certain with dwarf trees that the severe pruning will not cause the growth to be too vigorous for fruit-bud formation. It would seem that dwarf trees continuously unpruned might become weak and die younger than with standard trees, but that by annual renewal pruning this weakening might be prevented. Whether or not the graft union would be weaker or the root system less well anchored in the soil would seem to depend upon the dwarfing stock used. With not all varieties is there a compatible dwarfing stock available. Sometimes with pears a compatible variety is worked on the dwarfing stock (quince) and on this is budded or grafted the variety desired. Dwarfing stocks will be discussed for the different fruits separately.

Propagating different kinds of fruit trees. *The apple.* Apple trees may be propagated by budding or grafting. When budding is practiced, the roots, usually branched ones such as are grown in France, are planted in the spring to be budded in late summer, the seedling tip to be cut back to just above the bud in the following spring; and so, if the tree is sold as one year old, the roots are in the nursery two years; if as two years old, the roots grow in the nursery three years.

When grafting is practiced, a straight or a branched root may have the small ends cut off, the remainder being used for one graft; the practice being called "whole-root grafting"; or a straight root may be cut into several pieces, each being used for one-piece root graft. If it is desired to have strong scion roots, with varieties that will root from the scion, piece roots are used with a long scion as shown in Figure 17. The grafts are, of course, planted in the spring and grow into straight shoots during the succeeding summer; branching as with budded trees if left in the nursery during a second summer. The root system of a grafted tree one year old has grown in the nursery only one year.

Since, with budding, the root system has grown in the nursery one year and is well established when the bud starts to grow, it is to be expected that, other conditions being alike, a one-year-old or a two-year-old budded tree will be larger than a grafted tree of the same age; but the nurseryman's soil will have been used one year longer; that is, the average tree will have cost more, but there may be enough more trees of the larger sizes to justify the added expense. Larger average trees will be obtained from whole roots than from piece-root grafts at a slightly higher cost. However, trees of a given size should be as good for planting when grown from piece-root grafts; and some experimental evidence furnished from trees sent out by the United States Department of Agriculture to various experiment stations and reported on by those of Alabama (Bul. 98), Oregon (Report, 1910, p. 38), and Pennsylvania (Bul. 134) indicates that trees grown from piece-root grafts, whether the top or the bottom piece of a long root is used, give as good results in the orchard as those from whole-root grafts. Mason and Jones (480) obtained similar results in Kansas. They report also the experience of Judge Wellhouse, who grew four hundred trees of each of three apple varieties from whole roots and as many of the same from piece roots, and, although the piece-root trees formed many scion roots and the whole roots none, after nineteen years the only apparent difference was the greater number of sprouts from the whole-root trees.

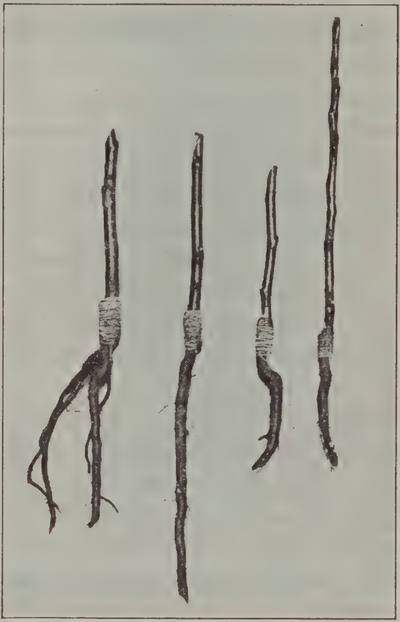

FIGURE 17. Showing apple grafts with "whole" branched root, "whole" straight root, normal "piece" root, and "piece" root with long scion to encourage scion rooting.

In the United States and Canada the French cider apple (crab) seedlings are generally used as stocks for apple trees. In some warm countries, such as parts of the Republic of South Africa, Northern Spy is used as a stock, since it is not injured appreciably by woolly aphis. Staniland (520) found that in England trunks and scion roots of Northern Spy and of several seedlings of French cider apples were so resistant that no galls were formed by woolly aphis. Hedrick (447) has called attention to the fact that apparently both Paradise and Doucin, the common dwarfing stocks, are merely small forms of *Pyrus Malus*, and that among French seedlings, when permitted to grow with their own tops, there are forms so small that, if used as stocks, they must have a distinctly dwarfing effect. Barker and Spinks (377) and Hatton (445) have shown that there is great difference in rapidity of growth among these seedlings and also great difference in nature of the root systems. Sax and Gowan (301, 302, and 513) seemed to find, from statistical studies of the behavior of trees in the orchard, and from examination of the root systems, that a considerable percentage of the small low yielding trees are so because of weak stocks. That not all was due to unfavorable soil was indicated by the fact that, in the case of isolated weak trees, though not with groups of weak trees, the roots of adjacent more vigorous trees were growing among the roots of the weak ones and the reverse. In other words, the roots of the weak tree were in the same soil with those of the vigorous tree.

If there are sold significant numbers of trees on such weak stocks, it seems desirable that precautions be taken to avoid loss. Several methods suggest themselves. Seeds could be selected from orchards containing only vigorous trees from which only vigorous seedlings would be grown. This would probably be very expensive. Or the stocks could be propagated vegetatively from desirable strains. Hatton (445) has described a form of the broad-leafed English Paradise stocks propagated by layering that dwarfs but slightly if at all, being nearly as large as the average French cider-apple seedling. He has also described a number of good strains of cider apples that can be propagated by means of mound or stool layering. It would require a long time, however, to propagate sufficient numbers from a single strain or from a considerable number of new strains to supply stocks enough for the trade. Further, propagation by this method is rather expensive, though perhaps not too expensive when the value of having uniformly vigorous stocks is considered. Another method sometimes used, as when Northern Spy is desired as the stock, is to bud on to scion-rooted trees, these trees having been obtained from piece-root grafts with long scions, the seedling roots having been removed at the end of the first year. This method also is expensive. If it should be found that roots will generally form on the base of a scion when the graft is made with the root attached an inch or two above the base of the scion, it might not be necessary to remove the seedling root until the tree had been dug for sale. The cost of obtaining roots of known inherent vigor might thus be reduced. Some preliminary studies suggest that such a method of making grafts very greatly increases the amount of scion root formation. Finally, it seems probable that trees that make a vigorous growth in the nursery can hardly be on slow-growing dwarfing stocks, and that, if one should purchase only trees above medium size for their age, whether they should be one or two years old, there would be little danger of obtaining trees with dwarfing stocks. Probably straight one-year-old trees would be most certainly of the age specified. However, even with straight whips one should be certain that they were not from weak trees left in the nursery and cut back to stubs in the previous spring. The most desirable practice would be to buy only from a nurseryman whose soil and nursery practices were known to the buyer. Rather small trees from a soil of medium fertility might be as desirable as any, provided they were above medium size in the particular nursery where grown; that is, provided they were known to be small not because of inherently weak stocks, but because of soil or climatic conditions or nursery practices, such as grafting instead of budding or using piece roots instead of whole roots.

In sections where winter freezing of the roots is rather common, it is important that the stock used be one that to the greatest extent possible tends to grow deep into the soil. We have seen that Hatton seemed to find that some of the Paradise strains tend to root as deeply as other kinds and some French cider-apple strains tend to be nearly as shallow rooting as the average Paradise strain. Scion roots of some varieties, such as Wealthy, McIntosh, Northern Spy, and even Ben Davis, are more resistant to low temperatures than are the roots of the average French cider apple. For such sections it would be well if the trees were grown from piece-root grafts with long scions, as shown in Figure 17, so that most of the roots, near the surface where the soil is coldest, could be hardy scion roots.

With the apple extensive use has long been made of trees dwarfed by working on what has been generally known as Doucin and Paradise stocks. Hatton (442, 444, and 445) has found under the names Paradise and Doucin many distinct types, some of which are as vigorous as the apple seedlings commonly used as stocks; that is, they would hardly dwarf trees at all. He found many gradations between these and the French Paradise that is a very small form and dwarfs very much.

Dwarfing seems to be a desirable practice in some of the northern parts of Europe. Thus, Pickering (502) gives the relative yields of four trees on Paradise and four on French crab stock with each of 117 varieties of apples. During the period from the eighth to the tenth year, inclusive, the yield on Paradise stock was 279 per cent of that on French crab, and during the period from the eleventh to the fourteenth year, inclusive, it was 180 per cent of that on crab stock. In the fifteenth year the yield was but 76 per cent of that on crab stock. Of course, this last may be only a fluctuation and it may require several years more for the trees on crab stock actually to surpass those on Paradise. It is possible that in this close planting the dwarf trees had the advantage. On the other hand, if the distance was great enough for normal development of the trees on crab stock, then the trees on Paradise stock could have been planted closer, and the benefit from dwarfing, when measured as acre yield instead of tree yield, would be greater than the figures indicate. His results suggest that in the climate of England dwarf trees may be very desirable. The size of the fruit on dwarf and standard trees was about the same.

Hedrick (447) reported observations during the first ten years of the life of three apple orchards in New York in which standard trees were compared with trees on Doucin and French Paradise stock. The trees on Paradise stock had borne less fruit to the tree during the first ten years, but, considering that they could be planted more closely, the acre yield would be larger. Fruit from the dwarf trees did not average better in color or quality than that from standards. The union with the dwarfs was not as good as with standard trees. Thus, thirty-one trees broke at the union on Paradise stock, four on Doucin, and none on standard stock; and 9.5 per cent of the trees on Paradise were killed by freezing against 4.45 per cent of those on Doucin, and 2.75 per cent of those on crab stock. The roots of the dwarf trees were nearer the surface, and this caused the loss of trees from blowing over as well as from freezing of the roots. The appearance of vigor was not appreciably greater with mature standards than with mature dwarfs. This would be expected, since, even in a good soil and with a strong growing stock, trees finally reach a condition when very little shoot growth is made. The dwarfs merely reach this condition earlier than the standards. The varieties making the best dwarf trees seemed to be McIntosh, Wealthy, and Lady, while Jonathan, Esopus, Grimes, Alexander, Wagener, Boiken, and Bismarck were satisfactory. Twenty Ounce was very unsatisfactory, and Baldwin, Rhode Island Greening, Rome, Ben Davis, Northern Spy, and Sutton were not entirely satisfactory. For commercial purposes in the northeastern part of the United States the dwarfs seem unpromising. However, Hedrick used the weak French Paradise. His results can be taken to indicate only that the strains used by him are not as satisfactory, as stocks for American varieties, as the average French cider-apple seedling. They do not necessarily prove that some of the better strains of the broad-leaf English Paradise described by Hatton might not be as good, with some varieties under some orchard conditions, as the French seedling. It might be that under many conditions a slight dwarfing, with closer planting of the trees, would give better results than with the average standard tree. Uniform dwarfing by such rather strong rooting strains that permits closer planting can hardly be as harmful as having a considerable percentage of dwarfing stocks among trees the larger number of which require wider spacing.

We are far from knowing the best stocks for apple trees of all important varieties under all conditions; or even under any particular set of conditions. However, until we have more knowledge the better plan would seem to be to use trees on the French cider-apple stocks, buying the larger grades of trees, preferably one year old, in order not to obtain dwarfing stocks; in very cold sections buying, if possible, trees so grown that there will be hardy scion roots.

With some varieties the trunks are easily injured in various ways. Thus, Tompkins King is very susceptible to winter injury. With such, generally a tree of some resistant variety is planted and top-worked in the orchard to the desired variety. Some think that, even when there is no such susceptibility to injury, top-working the average variety on trunks of a very vigorous variety may cause better growth. Thus, Stewart (709) seemed to find a rather marked difference in growth of apple trees when top-worked on different varieties. Paragon gave the best results of those on which other varieties were top-worked with Tolman, Northern Spy, Champion, and Wolf River next in order, all but Wolf River giving better growth than nursery trees of the same varieties not top-worked. Only four trees each of Jonathan, Tompkins King, and Grimes were used with each kind of stock, and so the experimental error involved may have been as great as the differences. It should be borne in mind that, unless there were scion roots from the trunks, the roots of these trees were all of the French cider apple. The influence on top growth exerted by the varieties on which the others were top-worked was exerted only by the trunks. Assuming that the stock affects the scion only by its influence on the water supply and on nutrition, the trunk of one variety might be better than that of another if it were more compatible with the stock or with the scion. And the trunk might influence the water supply directly, by the amount of resistance offered to water movement, or indirectly, by its effect on root growth. Thus, a very slow-growing trunk might not have sufficient conducting tissue for the movement of elaborated materials to the roots or of mineral nutrients to the top. Using a slow-growing trunk between the roots and the top might possibly be like cutting out strips of bark to reduce the phloem area. It would seem, however, that the difference in trunk vigor among the varieties might have to be rather large to influence measurably the growth of the tree by either of these methods.

The pear. In the eastern part of the United States pear trees are usually worked on French grown seedlings. These are primarily of *Pyrus communis*, though it does not seem improbable that some of *Pyrus nivalis* may be found among them, since fruit of the latter species is used for cider and the seeds to be planted are obtained from cider mills. Howard (458) found by inquiry among nurserymen that, in California in 1918, 63 per cent of the pear trees were being worked on Japanese seedlings (*Pyrus serotina*). This was then being used because of the susceptibility of the French seedling roots to pear blight and to the supposed resistance of the Japanese stock. However, the Japanese stock has been found somewhat disappointing in that State. The sprouts are nearly as susceptible to blight as those of the French stocks. Further, the latter seem to be resistant to the oak root fungus (*Armillaria mellea*), while the Japanese stocks are not; and French roots are considerably the more resistant to wet soils and to alkali. The Japanese stock, however, is the more resistant to root aphis. A survey made recently showed that, in 1923, 45 per cent of the trees were propagated on French stocks, and only 41 per cent on Japanese stocks. *Pyrus ussuriensis* and *Pyrus Calleryana* are highly resistant to blight, and a considerable number of trees are being worked on seedlings of these forms. Old Home and Surprise, two varieties very resistant to blight, are sometimes used, being budded or grafted on French roots and on the shoot obtained the desired variety is budded.

Not many dwarf pear trees are grown in America. In California, Howard found in 1918 that only about 4 per cent of the trees propagated were on dwarf stock. In 1920, however, about 9 per cent were on the quince. Quince roots seem to be resistant to the root aphis, prevalent in some sections of California; and some growers have found dwarf trees profitable. When dwarf Bartletts are desired, the quince stock is first worked to Beurré Hardy and then to Bartlett. A considerable number of pear varieties are not highly compatible with the quince, and such double working with a compatible variety intermediary is necessary. Hatton (443) finds a considerable amount of variation among quince stocks used in England for pears, some being too weak in growth and some not rooting readily from cuttings or layers. He thinks the true Angers quince the best now available. He is studying different strains as to vigor and compatibility with different pear varieties. With uniform stocks propagated vegetatively that are not too weak, dwarf trees might be found desirable. With their low spreading growth, they are more cheaply managed. They come into bearing young; and, since there are more trees to the acre, the first few crops might be more profitable than with the smaller number of standard trees. The trees should bear more nearly uniformly than trees on the variable pear seedling stocks.

The peach. With the peach there seems not to be as important problems concerning stocks as with some other species. Nearly all of the trees are worked on peach seedlings. Formerly seed of unimproved strains were used, many being obtained from the mountains of North Carolina. At present, however, according to Hedrick *et al.* (165), many of the seeds if not most of them are obtained from the canning factories and dry yards. This gives seedlings with differences in vigor about as great as exist among the varieties used for canning. It also makes the nurseryman trouble in that some do not take the bud readily. Hedrick thinks that if a place can be found where *Prunus Davidiana* fruits well so that enough seed can be obtained, it may prove to be a good stock. In California, this stock is found considerably more resistant to alkali than other peach stocks. Howard (458) found that 91 per cent of the young peach trees being grown in California in 1918 were on peach roots with the other 9 per cent about equally divided among almond, apricot, and Myrobalan. The almond roots were thought by some to adapt the peach to dry soils and the Myrobalan roots to adapt it to wet soils. While the former view is questionable, the latter seems probable. However, we do not seem to have conclusive evidence that peaches on Myrobalan stock would be commercially profitable in wet soils; and the union is liable to be bad.

The plum. Howard (458) found in California that of ordinary Domestica and Salicina plums 60 per cent were on Myrobalan stock, 37 per cent peach, and 3 per cent on almond. With prunes, 64.3 per cent were on Myrobalan, 23.3 per cent on peach, 11.4 per cent on almond, and about 1 per cent on apricot. Hedrick *et al.* (163, p. 114) find that in the United States by far the greatest number of plum trees are on Myrobalan stock, though the peach is often preferred for the Japanese plums. In sandy soils, especially in the Atlantic States south of Pennsylvania, the peach is preferred for those Domestica varieties with which it unites well. In the northern Mississippi Valley States *Prunus americana* is preferred as a stock, since the roots of this species will endure lower soil temperatures than will those of the other species. In Oklahoma, Texas, and New Mexico rooted cuttings of Marianna are used. In some sections of New York the Saint Julien is used. It is thought to produce trees of longer life than those on Myrobalan, and with deeper feeding roots that are adapted to more soil types and do not sprout so badly. Saint Julien is propagated by layers in France and Italy and the stocks are difficult to obtain in America. The trees also start slowly in the nursery. Except in the Pacific States so few plums are grown that probably only the more evident advantages and disadvantages of a stock could be learned without extensive and careful experimentation. Hansen (441) thinks that *Prunus Besseyi* may be very desirable as a dwarfing stock and as a stock for cold regions, though his experience was not very satisfactory. Trees on this stock are sometimes offered by nurserymen.

Waugh (531) made some studies with stocks for plums in which he seemed to find *Prunus americana* and *Prunus hortulana* promising. Hedrick (448) grew plum varieties of a number of species on roots of Americana, Marianna, Myrobalan, Saint Julien, and the peach. The Domestica varieties Bradshaw, Grand Duke, Italian Prune, Lombard, and Reine Claude, and the Insititia varieties Shropshire and Drap d'Or, were slightly better on Myrobalan roots than on any of the others; the Japanese varieties Abundance and Burbank did about equally well on Myrobalan and peach roots. Munsoniana and Hortulana varieties seemed slightly better on Marianna than on others, while the one Americana variety seemed to be grown slightly better on Americana than on other roots. All kinds did reasonably well on Myrobalan roots.

Hatton (445a) says that in England there are several kinds of stocks including Myrobalan and Saint Julien that are used somewhat indiscriminately for plums, peaches, nectarines, and apricots. He is studying the value of these stocks for different English varieties of stone fruits. Myrobalan and Saint Julien seemed to be compatible with a rather large number of varieties. But with both Myrobalan and Saint Julien he found a number of types, some of which seemed more promising than others. A few English varieties of plums, such as Pershore, are propagated on their own roots, stool layering being very successful.

The cherry. The two stocks mainly used for cherries are *Prunus Mahaleb*, and seedlings of *Prunus avium* known as Mazzard. Howard (458) found that 71 per cent of the cherries propagated in the nurseries of California are on Mazzard, 26 per cent on Mahaleb, and 3 per cent on other stocks. This is probably because the sweet cherry is of so much the greater importance in California. Hedrick (164) says that probably 95 per cent of the cherries grown in this country are budded on Mahaleb stocks. Yet he says that it seems to be the opinion of the growers of California, Oregon, Washington, Michigan, and New York that trees on Mazzard stock are more productive and profitable than trees on Mahaleb. Since the Mazzard is so seldom used for sour cherries, it seems rather doubtful if growers have observed the behavior of enough sour cherries on both stocks under like conditions for their views to be trustworthy. From the experience of growers, Hedrick reaches the following views: Mahaleb is the more hardy; Mahaleb tends to dwarf the trees to some extent; trees on Mahaleb stock come into bearing sooner; the size of cherry fruit is not influenced by the stock; better unions are made with the Mazzard; Mahaleb is adapted to a wider range of soils; while the evidence is conflicting, it seems probable that the tree will live longer on Mazzard stock; varieties on Mazzard seem to be more productive than on Mahaleb. However, later Hedrick seems to be finding Mahaleb certainly the better stock for sour cherries and probably the better stock for sweet cherries in New York.

Concerning the first of Hedrick's statements, Carrick (963) has shown by laboratory studies that the roots of Mahaleb are more resistant to low temperature than those of Mazzard. Concerning the second point we cannot be so certain. Howard (459) is growing many trees of Napoleon cherry on both Mahaleb and Mazzard stock. By the time the trees were four years old, those on Mahaleb were fully as large as those on Mazzard stock. In fact no difference was to be observed between the trees on the two stocks. Further experience may disclose some differences. Concerning the other conclusions of Hedrick, more evidence is needed before an opinion is justified. It is, of course, well known that much better results are obtained in the nursery when Mahaleb roots are used; trees on the Mazzard stock, therefore, cost the more. For sour cherries, trees on Mazzard stocks may not be worth more. We know only that good results can be obtained with either stock.

Other stocks are sometimes used. In parts of Japan, cherries are said to be worked on a strain of the Japanese Flowering cherry. In America, the Western Sand cherry, *Prunus Besseyi*, is occasionally used as dwarfing stock. Sour cherry (*Prunus Cerasus*) roots are sometimes used, and Hedrick (164) suggests the hardy Russian strains of sour cherries as stocks for cold sections. However, Mahaleb roots are probably hardy enough for any climate in which sweet or sour cherries can be grown.

The apricot. Howard (458) found that in nurseries in California, 56 per cent of the apricots propagated are on apricot roots, 27 per cent on peach, 13 per cent on Myrobalan, and 3 per cent on almond. Except where the apricot is more subject to injury from certain burrowing animals, such as gophers, no evidence from experience seems available to indicate whether the peach or the apricot stock gives the more desirable tree. Myrobalan is used to adapt the tree to wetter soils.

The almond. Howard found 56 per cent of the almonds propagated in California on almond roots and 44 per cent on peach roots. Nurserymen were agreed that Myrobalan does not make a good union with the almond.

Citrus trees. According to Hume (835) the principal stocks for citrus trees are sour orange, sweet orange, pomelo, rough lemon, and the trifoliate orange, the sour orange being the hardiest with the exception of the trifoliate orange. According to Coit (795) the demand in California is about 85 per cent for sour orange, 9 per cent for sweet orange, 5 per cent for pomelo, and 1 per cent for the others. The trifoliate orange seems valuable as a stock for the Satsuma orange. For others it seems to dwarf to some extent, though Bonns and Mertz (390) did not find a marked dwarfing effect on Navel and Valencia orange trees in California eight years after planting; with Eureka lemon the dwarfing was very marked; the pomelo seemed satisfactory for both oranges and lemons. Webber (537) has made a study of the variation in growth of seedlings of sour and sweet oranges to be used for stocks and the effect on the growth of the young trees after budding. He finds that, after two years of growth in the orchard, the trees on roots of weakly growing individual seedlings continue to be smaller than those on roots of vigorously growing individuals. He thinks it would be desirable to select seeds from vigorous trees having no adjacent trees of low vigor, and in the nursery to discard both the weak seedlings and the trees that make a weak growth after budding.

The grape. Grapes of American species are propagated by cuttings or by layering; that is, they are on their own roots. Vinifera grapes also were grown on their own roots until *Phylloxera* was introduced from America into Europe and finally into the Vinifera grape region of California. When this insect first began to do serious damage to vineyards in France, an effort was made to obtain resistant varieties by crossing European varieties with American species that are not seriously injured by this insect. The effort was not very successful, though a few varieties were obtained giving fair results as wine grapes. Better results followed the use of resistant American varieties as stocks. The American species most resistant are *Vitis rotundifolia*, *Vitis rupestris*, and *Vitis vulpina*, *Vitis Berlandieri*, and some others also are so resistant that little injury is suffered. *Vitis rotundifolia* cannot be used as a stock because it does not readily form roots on cuttings. When American species were first used in Europe as stocks for Vinifera varieties, the results were not altogether satisfactory. The growth on some was too weak, some were ill adapted to the soil of certain regions, and some caused too vigorous growth with certain varieties. After very extensive breeding and experimentation, there has now been found a reasonably satisfactory stock for each important French variety. These stocks have not always been found best for the same varieties when grown in California (Bioletti, 388, and Flossfeder, 430).

Hedrick (446a) seemed to find growth and fruiting with a number of varieties of Labrusca and Labrusca × Vinifera grapes, such as Agawam, Barry, Concord, Delaware, Herbert, Niagara, and others to be somewhat better when the vines were grafted on Saint George, Riparia-Gloire, and

Clevener — forms used as stocks in California — than when they were on their own roots. Gladwin (434a), who continued this work, found Delaware, Campbell, Niagara, Iona, and Catawba almost certainly much better in growth of vines and yield and quality of fruit when grafted on Clinton or Riparia-Gloire stocks than when on their own roots. With Concord there was less difference.

The grape may be grafted in the field by either cleft grafting or whip grafting on to the stem cut back to a stub beneath the surface of the soil. Cleft grafting is used with stems two thirds of an inch in diameter; whip grafting with smaller stems. Cuttings planted one year should be ready to graft by the following spring. The grape may also be bench grafted by using a cutting of the stock about ten inches long, the cut at the bottom being made through a bud and that at the tip one and one half inches above a bud. This space above the bud is for convenience in grafting. Every bud on the stock is removed. The scion may contain one bud or more. Scions with only one bud are very convenient, since scions all of the same length can then be used. There should be two and a half inches below the bud and at least one and a half above it. The stock and scion may be united by whip or tongue grafting much as with apples or pears, the union being tied with raffia; or a graft without a tongue may be used, the stock and scion being held together by a piece of wire pushed into the pith of each. It is best to tie the grafts into bundles of about ten and place them in a callusing bed, which is a pile of sand usually on the south side of a wall or building. Bioletti (388) found better callusing and rooting with grafts in sand containing five to ten per cent of moisture than in drier or wetter sand. Planting is much like that with apple grafts except that the scion is covered with a gently sloping mound of earth so the union will not be dried out. Bioletti had appreciably better success in bench grafting than in field grafting.

Summary. In many ways the most desirable vegetative propagation is by some of the practices, such as root or stem cuttings or layers, by which the plant is on its own roots. Methods have been discovered by which the formation of roots with plants that are regularly propagated by one of these methods can be increased, but no discovery has been made, unless it be the improved methods of making root cuttings, that promises appreciably to increase the number of species so propagated. With most of the tree fruits, propagation by budding or grafting on certain stocks seems to be unavoidable. Budding is nearly always practiced with all of these except the apple and the pear. Whether budding or grafting is practiced with apples and pears is a problem of the nurseryman only, the tree obtained by either method being equally good for planting. With woody plants, at least, no influence of stock on scion has been demonstrated except such as may be explained through the effect of a weak or a vigorous root system on the supply of water and mineral nutrients, or on the use of organic food, and through the adaptation of the root system to a particular soil. The use of dwarfing stocks seems to be more desirable in sections such as England, where the growing season is short, cool, or cloudy, than in any fruit section of the United States. However, we have no conclusive evidence that slightly dwarfing stocks might not be desirable with some fruits in America. The compatibility of stock and scion is not determined by nearness of botanical relationship alone, and there is no means of determining, except by experience, whether or not a stock and scion fairly near in botanical relationship will be compatible. Not only does the stock influence the vigor of growth of the scion, but the scion also influences the growth of the stock. It is probable that small fluctuations in vigor of stock are nearly obliterated by this influence of the scion. Nevertheless, it is probable that with all tree fruits, except quinces and dwarf apples and pears the stocks of which are propagated vegetatively, there is some loss from variability of the seedling stock used, though, on account of the great experimental error with trees, and particularly in tests of stocks in which the experiment must begin with the young tree and be continued through its life, it would probably be difficult or impossible to determine how great such loss might be. With Vinifera grapes stocks resistant to *Phylloxera* are necessary in most sections. Since these stocks are propagated vegetatively, however, it is possible by breeding to develop stocks well adapted to each important variety and each general soil type, and free from strains or individuals of low vigor, much more quickly than if the stocks developed were grown from seed. There are available for use as stocks many strains of apples that root from mound layers, and, if it should be found desirable, stocks to be propagated vegetatively could be developed for all important varieties of apples and for different soil types. The process would be much less rapid than with grapes, however, because the experimental error in studying the adaptability of varieties to certain stocks would be much the greater with apple trees. Probably with most kinds of tree fruits, the best means the grower now has available for obtaining uniformly rather vigorous stocks is to buy trees of the larger grades of a given age from the nursery; that is, the medium to large trees one year old or the medium to large trees two years old.

CHAPTER 7

TREATMENT OF ROOTS IN TRANSPLANTING

Condition of roots at transplanting. When the tree is removed from the soil, the root hairs are destroyed. This in itself should be harmful for only a short time, since the life of the root hair is probably very brief. With the transplanted tree, however, the tips of most of the small and large roots are destroyed, and, before new root hairs can be formed, new roots must start from various points on the old root system. There is always some delay in the starting of the buds of the transplanted tree. That this is due in part to the limited water supply is suggested by the work of Goff (437), who seemed to find marked beneficial results from pressure of water conveyed from an elevated vessel through a rubber tube attached to a root of a newly transplanted tree. It seems probable that as good results would have followed if the tube had been attached to a branch. Sometimes trees do not start growth until mid-summer or later, after being planted in the spring; and occasionally pecan trees do not start until the succeeding year. It seems probable that this may be due not entirely to continuous inability of the roots to absorb water, but partly to some condition in the tissue resembling the rest and caused by some influence such as a high temperature or loss of water during winter, or by the water deficit following transplanting.

It is often taught that great care should be taken to preserve the small fibrous roots in planting trees. The opinion of some seems to be that these fibrous roots will continue to grow from the end. However, if the root tips are destroyed, new adventitious roots must start from fibrous roots in the same way that they would start from larger ones. Small roots will suffer more from drying and other injury in transplanting, and will probably be weak. It might, therefore, be better for the tree to have its stored food supply used in making new roots from the better, larger roots. Pickering (500) seemed to find that this is true. Thus, from trees with all fibrous roots below one millimetre in diameter removed, he obtained 39 per cent more growth during the first year after planting, and an average of 13 per cent more during the first three years after planting, than from trees without these roots removed. When larger roots were removed, however, the growth was reduced, the growth from trees with roots two millimetres in diameter or smaller removed being only 69 per cent of that made by trees without such root removal. By the end of three years, however, the growth on these trees was 92 per cent of that on the trees without root removal. These results were with young nursery trees. With beech trees ten years old the removal of even small fibrous roots was injurious. This was probably because these old roots were not in condition rapidly to form new adventitious roots. With apple trees Barker (374 and 375) also found no reduction in growth to follow the removal of all fibrous roots, the new roots being from the crown or from the larger roots. Pickering thinks that trees with many fibrous roots may be the better kind to plant, even though the smallest roots die or are removed; the same condition in the nursery that encouraged the formation of fibrous roots may keep the larger roots in a better condition to send out adventitious roots after transplanting. This condition of the old roots is brought about with some trees by much repeated transplanting in the nursery or by much pruning of the roots.

Exposure before transplanting. Pickering (500) studied the effect of the exposure that trees undergo after being dug before they can reach the buyer and be planted. Eighty trees were dug from the experimental farm nursery and half of them replanted the same day, the other half being left under cover in a shed during four days. Dwarf and standard apple and pear trees received each treatment. During the first summer in the orchard the exposed trees made about twenty per cent less new wood than the unexposed ones. Very often trees must undergo exposure more injurious than would be four days in an open shed in a humid climate like that of England. Yet results are generally satisfactory when care is taken to avoid drying, even when the trees must be shipped more than a thousand miles. An orchardist would seldom be repaid for growing his own trees merely to avoid the small loss of growth during the first year that results when the trees are obtained from nurserymen.

A considerable amount of discussion is heard concerning the injury to the trees that results from their being kept through the winter in bins in the nurseryman's storehouse. However, it is nearly impossible for a nurseryman to do a large business without a storehouse, and, in high latitudes at least, many varieties of fruit trees may be kept in a much better condition in a good storage house than in the open field. Peaches, sweet cherries, quinces, such varieties of apples as Baldwin, Rhode Island Greening, Tompkins King, Stayman, Winesap, and others, and nearly all varieties of pears, may, if left out of doors in a cold section, be seriously injured by freezing in the winter. Further, while the injury, when there is any, from exposure before planting will generally not be apparent after a year or two, trees frozen in the nursery during the winter preceding their being dug may never make satisfactory growth. Then some fruit trees are more cheaply grown at lower latitudes. It is not convenient to use these at high latitudes unless a storehouse is available. They are likely to continue growth too late in autumn and start growth too early in spring for planting at higher latitudes, but they can be shipped to higher latitudes in early or late winter and held in a storehouse until planting time.

Where the winters are steadily cold, fruit trees should not be injured appreciably by being held in storage. In the climate of New York, the temperature in a good storehouse may be held to very near the freezing point from the time when the trees are dug, in autumn or early winter, until nearly planting time. A New York nurseryman, who keeps temperature records in his storerooms each year, found the maximum temperature on December 1st, while the rooms were still being opened for the taking in of trees, to be 50° F., and the minimum 34° F. After that, the maximum for the month was 36° F., and the minimum 32° F. The thermometer was below 36° F. the larger part of the time during December, January, February, and March. This nurseryman keeps his peach trees actually frozen during a large part of the winter. As soon as the trees are dug and the bins are filled, they are covered with wet shavings or a similar material and the ventilators are opened often enough to keep the trees frozen without permitting the temperature to go low enough to kill the roots. (Probably the temperature of the roots of no kind of fruit trees should be permitted to go below 25° F.) Peach trees kept in this way certainly make excellent growth; and in experiments involving rather large numbers of trees, I have been unable to detect any bad effect of such storing. Even when the trees were taken from the storehouse so late that the buds had started, uniformly good growth was made. In one year, trees that were planted in the fall at Ithaca, New York, and protected from freezing, made a slightly earlier start than those that had come in the spring from the storehouse, but there was no measurable difference in the total annual growth. Apple trees kept in this storehouse, not frozen, but at the temperatures mentioned above, have made uniformly good growth. Not all storehouses are kept at such satisfactory temperatures, and a man buying trees that have been kept in storage should know something about his nurseryman. The lower the latitude and the more warm days there are in winter, the more difficult it will be to keep trees in a storehouse. During warm periods it is hard to keep the humidity high enough or the temperature sufficiently uniform to avoid drying the roots. Further, at the higher temperature respiration will be increased, and the stored food supply of both roots and top reduced. Then, from what we have learned in Chapter 3, the temperature of the New York storage house mentioned, 32° to 40° F., is probably about the best one for bringing trees completely out of the rest period so they will start growth vigorously in the spring.

One nurseryman in southern Missouri claims to keep his trees in a commercial storage plant. Unless the cost should be prohibitive, such a system of storage would seem to be excellent. Where storage houses are available, even though they are not used throughout the winter, they may sometimes be convenient for holding trees that may be received from lower latitudes before the ground is thawed in colder sections. Thus, excellent results have been obtained when trees received at Ithaca, New York, in January, from California nurseries, have been held in a commercial storage house at a temperature of 32° F. until planting time. If the temperature of the room is a few degrees above 32° F., there will be slight growth of the buds and a considerable amount of cambial growth around the base of the buds. Such tissue becomes very tender; and so trees held in storage should not be planted out of doors before danger of temperatures as low as 18° to 20° F. has passed.

Strawberry plants received in ordinary crates in April, and held in cold storage until June, have made excellent growth. Since strawberry plants develop exceptional root systems in certain parts of Maryland and the Ozark regions, it would seem that more use might be made of this method in retailing plants in the North. It is more important with strawberry plants than with trees that the storage temperature be held near 32° F.; for at temperatures but little higher there is some growth and fungus injury. How much below 32° F. the temperature may safely be has not been determined; but, certainly, a temperature of 28° F. would not be injurious unless the plants had been exposed to a temperature a few degrees above 32° F. long enough for some growth to be made.

Distribution of new rootlets. It seems to be the view of many writers that new rootlets on trees recently transplanted are formed mainly at the end of the old roots. Pickering (501) found many roots starting from other positions. Thus, of 15,642 new rootlets from 84 young apple trees, 49 pears, and 6 plums, 71 per cent started from the body of the old roots, and 14 per cent from the stem of the tree. In another experiment, however, with 50 apple trees two years old, 41 per cent of the roots started from within one half inch of the end of old roots, and 35 per cent from the stem. With gooseberries and currants a little more than 50 per cent of the new rootlets started from within one half inch of the end of old roots. Barker (375) found that, with Paradise apple roots newly planted in a rather compact soil, nearly all new roots were formed on the central part near the surface of the soil; but, with the same kind planted in sand, new roots formed on all parts of the old root system. Aeration seemed to be the most important feature in determining the distribution of new roots. With stocks that do not form new roots on the older parts as readily as does the Paradise stock, it is probable that even lack of aeration would not have caused such a grouping of new roots near the surface around the central part. In other words, the aeration of the soil and the nature of the stock may determine the distribution of new roots on newly transplanted trees.

Effect of cutting back roots in planting. Since such a large proportion of the rootlets start from along the old roots, it seems possible that, by leaving most of the old root system, more new rootlets might be formed and the tree might thus make better growth at the start. On the other hand, since the roots from the old stem are the stronger, the new root system formed might, temporarily at least, be slightly better if a considerable part of the old root system is cut away, thus encouraging rooting from the stem. The extreme application of this possibility is made in the Stringfellow method of pruning, where practically all of the roots except the central one are cut away, the top being cut back proportionally. Pickering (500) has studied rather extensively the effect of removing parts of the roots in planting. His results generally indicate that, when the roots are cut back to the extent that forty or fifty per cent of their length is removed, a considerable reduction in the growth of the transplanted tree results; but, when in cutting back only ten to twenty or perhaps even thirty per cent of the root system is cut away, there is no harmful result: in fact, there seems to be a slightly beneficial result, though this apparent benefit is probably within the range of experimental error. Card (405) planted twenty-five trees by the Stringfellow method, with the roots cut back about one half and the twigs one year old also shortened about one half, and twenty-five with the roots unpruned, but with the twigs shortened one half. These were planted in the rather arid climate of Nebraska in the spring of 1896. In the spring of 1897 only two trees planted by the Stringfellow method were in good condition, and by June, 1898, while half of the trees planted by the Stringfellow method were in fair condition, they were far behind those planted by the other methods. The trees planted without root pruning were in decidedly the best condition. The new rootlets had come largely from near the central root of the trees, just as they had where the roots were pruned back about one half. In fact, with trees whose roots were cut back one half and with those having no root pruning, more new roots grew from the central root than grew from the trees pruned by the Stringfellow method. In another series of experiments in the same State, Card obtained practically the same results, the trees without root pruning making the better growth. In Rhode Island, the same author (406) found root pruning, even by the Stringfellow method, less injurious. Trees with part or nearly all of the old roots pruned away at planting gave excellent results, though not better than the ones without root pruning. The general conclusion seems to be that there is no benefit to be derived from pruning back the roots, and, although a small amount of pruning has little influence, harmful effects may follow severe root pruning before planting. In a humid climate, like that of England or of Rhode Island, root pruning, while not beneficial, is less harmful than in a dry climate. Probably, in nearly all sections there are years dry enough for severe root pruning to be injurious.

Effect of cutting off broken ends of roots. Great care in cutting off the ragged ends of roots in transplanting is often recommended. Some suggest that the tree be turned upside down and the cut made outward, so that when the tree is erect the cut surface will be flat against the bottom of the hole. The work of Card quoted above, in which transplanting with no pruning of the roots gave best results in Nebraska, and as good results as any in Rhode Island, would indicate that these rough ends are not injurious to the tree. Pickering (501) has made a considerable study of the effects of leaving the ends of the roots rough as they come from the nursery. While his results are somewhat conflicting, they certainly indicate that roots with roughly broken ends give as good results as those with which the ends have been cut smooth; and it seems certain that there is no advantage to be derived from pruning the roots in any way in planting, unless there are roots twisted around each other.

Effect of bending or bruising the roots in planting. Much advice has been given as to the care to be taken in straightening out all roots and avoiding any bending or other injury to the roots in planting. These precautions seem to be of less value than might be expected. Thus, Pickering (500) planted trees with the roots bent downward and tied before planting, and others in which the roots had many notches cut into them. With both there was a slight deficiency in growth during the first year, but growth of the trees with the bent roots was practically normal during the second year, while that of trees with notched roots was slightly above normal. In other experiments the effect of bending and twisting the roots did not seem to be injurious.

From the work of Noll (493) and others, it might be expected that when the roots were bent the larger numbers of new roots would be found on the outer side of the sharpest curves; and it might be expected that new roots would tend to grow in largest numbers from the callous tissue formed where roots were injured. However, Pickering did not seem to find more new roots at such positions; but the bending and other injury seemed to cause more new roots to start from the central root. Barker (374), however, while finding the new roots mainly from the central roots with trees planted in compact soil, seemed to find that on trees planted in sand more roots formed from the new tissue covering wounds than from other parts of the roots. It may be that in a poorly aerated soil the lack of oxygen is of such predominance as to obliterate other influences such as polarity.

With some trees planted at Cornell University, bending the roots downward and planting in a narrow hole seemed, during four years of growth, to cause a smaller top growth than with trees planted in holes large enough to permit the roots to be spread in their normal position; but bending the roots upward and planting in small holes did not seem to reduce growth. The soil was rather compact; and the holes had to be especially deep for the trees with the roots bent downward. It may be that the reduction in growth was due to the fact that some of the roots were in soil too poorly aerated for them to be very effective in supplying water and nutrients to the tree.

While bending, bruising, or twisting individual roots in planting does not seem to be injurious, twisting two roots around each other or even bending them in such a way that they cross each other near their points of origin may cause injury after the roots have become large enough that, by pressure, they restrict growth.

Effect of great firmness of the soil around the tree. Pickering (500) planted trees in holes only large enough to get the roots into them even with twisting and bending. The soil around the roots was then firmed with a heavy rammer until it was thoroughly puddled and would shake like a jelly at each stroke of the rammer. In a heavy clay soil the rammed soil was more compact than that around it, even during the third year after planting. In a very light, sandy soil the effect of the ramming on the firmness of the soil was temporary, and in such soils ramming had little influence on tree growth.

With medium heavy and heavy soils, however, there was a very marked influence on the growth of the trees. In a rich, stiff soil on the clay-with-flints overlying chalk at Harpenden, the benefit, as measured by additional twig growth on 89 dwarf and standard apple and pear trees in soil rammed at planting, was 86 per cent during the first year, and 118 per cent during the second year. At Ridgemont, in another heavy clay soil, with a much larger number of trees, the benefits during the first year ranged from minus 4 per cent to plus 110 per cent, and during the second year from plus 3 per cent to plus 151 per cent. In five out of seven sets of trials in this soil, the benefits were 15 per cent or above during both the first and the second years. At first it was thought by Pickering that these benefits to annual growth could not continue, but in 1916 he reports two sets of experiments in which the trees were left. In one the average annual superiority in growth during the first seven years in the orchard was 49 per cent in favor of the ramming process, while in the other, during eight years, it was 43 per cent. With gooseberries and currants also, he found benefits from ramming, and with raspberries when only the behavior of the old cane was considered; but, when the new suckers were considered, the effect was injurious. Of course, it would be expected that such great firming of the soil would interfere with the growth of new suckers within the firmed area. He thinks the beneficial effect of ramming may have been due to the fact that, since the soil particles with their moisture films were pressed more closely together, a larger percentage of the surface of the old roots was brought into contact with moisture films.

It should be emphasized that these results were obtained when the hole was so small as barely to contain the roots; the new rootlets formed were soon out of the rammed area. If the holes had been much larger, so that the new rootlets would have had to grow through a considerable area of this compacted soil before entering a soil in good tilth, it is highly probable that no such benefits would have been observed, and even that injury might have resulted.

In heavy wet London clay soil, Pickering found ramming to result in chemical changes in the soil that injured the roots. Ramming a soil while it is very wet should almost certainly prove injurious. In fact, I have observed injury to young peach trees from packing a wet rather compact silt loam around the roots only as firmly as it is possible to pack it with the foot. When trees must be planted in wet soil, it should be packed only lightly so that it will become aerated as soon as possible.

At Cornell University, with trees planted in small holes, ramming even a compact clay loam with a heavy iron tamping stick until the soil shook like a jelly has not been clearly injurious; but it has not given better results than followed merely firming the soil with a rather light wooden tamping stick or with the shoe heel. Barker (375) seemed to find ramming injurious in a rather compact soil at Long Ashton, England. He speaks of spreading the roots; and it is probable that he did not follow the precaution of Pickering in planting in very narrow holes so that the new roots would have to grow through only a rather thin layer of compacted soil. However, until we know more about the effect of ramming in many different soil types it would seem wise to follow the established practice of pressing the soil rather firmly about the roots, but not to ram it into a jelly.

Effect of depth of planting. One of the most difficult problems to settle experimentally is the depth at which fruit trees should be planted. With young trees deeply planted, the roots will unquestionably be in soil where the moisture supply is more nearly uniform, and in dry times more abundant. On the other hand, roots are very greatly influenced in their growth by the degree of aeration in the soil. Almost uniformly the better root systems are found in the well-aerated soils. If the trees are planted so deep as to place the roots in poorly aerated soils, the root growth will certainly be greatly inhibited if not prevented. In fact, if placed in the soil below where the supply of available nitrogen is adequate, root growth will be reduced. It will be evident that the bad effect of too deep planting will be different for different species and varieties, just as the roots of some trees are more seriously injured by being in wet soils than are those of others. Results of experiments with deep planting, therefore, will be different to some extent in different soils and with different fruits.

Pickering (500) has studied the effect of planting four inches deeper and four inches more shallow than the trees stood in the nursery. In so far as the growth and development of the tree was concerned, there was, under his conditions, no difference. Of course, the more shallow roots would be susceptible to injury by the plough or cultivator, but with Pickering's orchard these trees seemed to sink into the ground, perhaps from their weight, as they grew older. Since the soil Pickering worked with was a rather heavy clay with which deep planting would be the most injurious, his finding no harmful effect from planting the trees four inches deeper than they stood in the nursery would seem to justify the conclusion that with nearly all soils it is safe to plant that deep. The danger of injury to the roots by the cultivator would thus be reduced. In the experience of Woodbury and Oskamp (737), during the first few years in the orchard, depth of planting had more influence upon the depth of the roots than methods of cultivation had. The view is commonly held that when trees are planted too deep, the roots tend to grow toward the surface. This may be true with soil so well aerated that deep planting will not be injurious; but Pickering finds that it is not true with trees planted in heavy clay soil; and growth in such a soil is greatly reduced by very deep planting. Assigning the value of 100 to the growth of standard trees planted with the roots 6 inches below the surface, that for growth of trees planted with the roots 12 and 24 inches was respectively 61 and 33.

Pickering's results with Paradise trees, which root from the stem, were very interesting. In several different types of soils, Paradise trees were planted so that the roots were 6 inches to 24 inches below the ground level. During the first season the stocks that were planted 12 inches deep showed a deficiency in growth as compared with those planted 6 inches deep, while those planted 24 inches deep showed a still greater deficiency. During following seasons, however, the reverse was true, those planted 24 inches deep showing a benefit of from 80 to 195 per cent, as a result of the deep planting, while those planted 12 inches deep showed a benefit of from 32 to 70 per cent over those planted 6 inches deep. An examination of the roots showed that, while the old roots had made very little growth or had even died, excellent new roots had started from the stem above the original root system. With this variety, which roots from the stem, it is probable that the benefit from deep planting is due to the greater stem area on which new roots may form. That the poor rooting from the part of the stem that was deep in the soil was due, not to infertility, but to insufficient aeration, is shown by the fact that when Pickering placed the rich top soil in the bottom of the hole around the roots, and the poor soil near the surface, the stems still rooted well near the surface, but failed to root at the bottom of the 24-inch holes.

Such deep planting would, of course, be dangerous with trees budded or grafted on Paradise stock as well as with trees on crab stock; for the stem would be not the Paradise stock but scion wood, and most of the varieties of apples grown do not readily root from the stem. The results, therefore, would generally be similar to those with the crab stock, where the deep planting was very injurious. There are varieties, however, that root rather easily from the scion. This seems to be true to some extent of Delicious, McIntosh, Chenango, and Northern Spy apples. I know of no experience indicating what might be expected from deep planting of such varieties. However, even with these varieties root formation from the stem is rather slow, and planting deep enough to injure the original root system would probably be injurious to the tree.

There seems little question, however, that deep planting may be desirable with some fruit plants. Currants root from the stem very readily, and experience seems to indicate that planting deep enough for some of the branches to be partly beneath the soil and to root, is desirable practice. This seems true, not so much because of the better growth obtained by deep planting, as because of the benefit from having more than one stem to the bush. The currant breaks very easily during the period of rapid growth in early summer, and with the bush form if one stem is broken there will be others left to bear at least a small crop. Then, too, the more rooted stems there are the sooner the plant will be large enough to occupy all available space and bear a maximum crop. Since gooseberries and grapes also root from the stem, it would be expected that deep planting would be desirable for them also. However, we have no experimental data as to the wisdom of deep planting with them. Certainly Vinifera grapes on resistant stocks should not be planted deep enough to weaken the root growth of the stock.

The effect of deep holes, trenching, and blasting. It is generally considered desirable to have the roots of fruit trees penetrate as deeply as possible into the soil. In the United States, to bring about this condition it is sometimes recommended that very deep holes be dug or that holes be blasted with dynamite; while in England trenching the soil rather deeply along the row seems to be practiced at times, the deep holes or trenches being filled with loose earth to the depth at which the trees are planted. Concerning the digging of deep holes, Card (405) and Pickering (500) found no beneficial result. If loosening the soil deeply would benefit the trees by encouraging deep rooting, then the method of trenching would seem particularly effective, since the soil would be loosened throughout the length of the row rather than just at the trees, and there would be less danger of causing water to stand around the tree roots. Yet the results of Pickering (500) indicate that the trenching not only failed to be beneficial, with dwarf or standard apple trees, but, in fact, while the vigor of growth was about equal on trenched and untrenched land, the yield on the untrenched land was the better. Pickering was, therefore, inclined to conclude that, with a heavy soil such as he had at Ridgemont, it is undesirable to force the roots deeper than the richer surface area.

In America the most widely advocated method of encouraging deep rooting is by blasting the holes with dynamite. Usually one third to one half a stick of low-grade dynamite is exploded at a depth of about twenty to forty inches in the soil. It should be said at the beginning that, unless the holes dug without the use of dynamite are very much larger than it is necessary for them to be, planting in holes made with dynamite is many times as laborious and expensive as planting by the ordinary method. The results of Farley (428), Call and Throckmorton (402), Clement (407), Woods (546), White (539), and Whitten (541), as well as of others, have in no case indicated that any appreciable benefit can be expected in either light or heavy soils from this use of dynamite. Farley seemed to find small benefit to peach trees during the first year. No such benefit was observed with apples, however, and that with peach trees was not large enough to be of importance when the trees came into bearing. Examination of the roots of both apples and peaches indicated that they were deeper where the trees had been planted in blasted holes. In planting the trees where dynamite was not used, furrows were run each way and the trees planted where the furrows crossed. Whether the soil around the roots would be as well firmed by this method as it would be if small holes were dug, we cannot say. At any rate, reports now available suggest that the benefits from the use of dynamite have not been permanent. That was true even with Farley's experiment with peaches, the one that has given the results most favorable to dynamiting. The soils in which his peaches were grown were probably not so compact that one would expect results from the use of dynamite. Yet he observed that the soil was loosened several feet around the point where the shot was made. That in which the pears and apples were grown was a heavy clay loam with a stiff clay subsoil. Both seasons in which his trees were planted are reported to have been rather dry. Most of the other experimenters have worked in a rather heavy clay soil.

It is in these clayey soils that the dynamite is supposed to be most beneficial in loosening and aerating; yet Call and Throckmorton seemed to find that, instead of loosening the soil for a great distance, there was a tendency for the soil to be somewhat firmed around the outer edge of the hole blown. If this were generally true, then if the season following the planting of trees by dynamite should be wet, there would be danger that free water would remain in the area influenced by the dynamite. This, of course, would injure the roots of trees; and I have had that experience with peaches and cherries, those planted by the use of dynamite showing more injury during a wet season than those planted in small holes dug with a shovel. In some of the experiments the number of trees lost during the first year after planting was larger where dynamite was used. Great care is always necessary in planting in this way, since it is easy to overlook holes deep in the soil. If these holes are left, the tree is liable to sink very much too deep, as the soil settles into them during rainy times following planting. These statements apply to humid sections where there is always enough moisture in clayey soil for dynamiting to cause compacting around the periphery of the area influenced. In sections such as California, with no summer rainfall, the work can be done when no such compacting can possibly result.

While we seem forced to the conclusion that in heavy clay soils in humid sections trees are not benefited by being planted in holes made with dynamite, and that in well-aerated soils there certainly can be no permanent benefit, it is not impossible that there may be soil conditions such that the use of dynamite will be beneficial. Occasionally in humid sections, and very commonly in sections where irrigation is practiced, there is a rather gravelly or otherwise desirable fruit subsoil beneath a layer of very compact soil like hardpan. It seems possible that, if the hard layer should be broken up with dynamite, the roots might penetrate the subsoil beneath, and the tree thus be benefited. It should be borne in mind, however, that we have no positive experimental evidence that the roots would penetrate beneath such a layer, or that the tree would be benefited if they did; unless the compact layer were broken up in nearly all the space between the trees. Aeration under such a layer would probably be better in a semi-arid section, where the water table is low and the subsoil dry during much of the year, than in a humid section. And the use of dynamite in such soils with an impervious layer over a good subsoil seems to have given better results in some sections of California than in humid regions. However the experience there has not been studied carefully and results seem to have been contradictory.

Season of planting. As we have seen in Chapter 4, the roots seem to grow in autumn until the soil is too cold for growth, and they seem to grow at a temperature near the freezing point. It seems probable, therefore, that, if fruit trees are planted in the fall, some new root growth will take place before the soil is too cold. The work of Card (405), Whitten (541), and Pickering (500) makes it clear that there may be a considerable amount of such root growth in autumn or early winter after fall planting. Such autumn root growth certainly should be of marked benefit to the tree in starting growth in the spring, since there would be a better water supply for the new foliage that would start as soon as growing temperatures were reached. The work of Card, Whitten, and Clement (407) indicates that appreciably better growth during the first season may sometimes be expected from fall planting, and in the experiments of Whitten rather marked beneficial results have continued to be shown after the tree has been planted several years. The results of Pickering were not especially favorable to fall planting except where the trees were planted in early fall. Both dwarf and standard trees made much better growth when planted October 30th than when planted December 3d, March 13th, March 30th, or April 16th. It should be said, however, that where the trees are bought from the nurseryman it is seldom possible to obtain them in time for early fall planting, and that if they are dug so early the wood is not properly ripened. For fall planting, particularly in northern climates, the wood must be well matured. Thus, if the winter following the early fall planting were mild, one would expect good results like those obtained by Pickering. On the other hand, if a cold winter should follow, it is possible that trees would be injured if dug so early that the leaves would not fall naturally but would have to be stripped from the trees. For States as far north as New York and Michigan, therefore, early autumn planting would seldom be advisable with any variety that does not cease its growth in the nursery especially early.

It would be expected that at the lower latitudes in which a fruit is grown, fall planting would be more desirable than at higher latitudes. There is less danger of winter injury and more time before freezing weather for the trees to be obtained from the nurseryman. Further, there is more time during early winter when the soil is warm enough for some root growth. Clement (407) found rather markedly beneficial results to follow fall planting in Canada, but his results are for plantings of only one year. In other years there might have been injury. I have had the opportunity to observe the effects of fall and spring planting of considerable numbers of trees in southern Missouri and in New York, and certainly the advantages from fall planting are very much the greater in southern Missouri. One of the greatest injuries that may result from fall planting is the lifting of the trees in the soil, due to the heaving that results from the freezing and thawing in late winter. In New York, fall planted trees are often rather seriously injured in this way. With some trees in the Cornell University orchard, instead of resetting after such heaving, the soil was merely packed firmly around the roots as they stood. This left the roots nearer the surface than they had been placed at setting, and it has been difficult to avoid injuring them with the plough. It seems certain that, if fall planted trees are found to heave in this way to any marked extent, they should be dug up and replanted in the spring.

In so far as experience indicates, most fruit trees will withstand transplanting better while they are dormant. However, Whitten (541) seemed to have best results with the American persimmon, the black walnut, the pecan, the hickory, and the chestnut, as well as a number of species of evergreen, when transplanting was done just as the new growth was pushing out in spring. Others have thought they observed beneficial results from delaying the transplanting of evergreens and the persimmon until some growth had been made, but no exhaustive study of the problem seems to have been made, and in some climates, at least, persimmon and nut trees are readily transplanted while fully dormant. At Cornell University, pecan trees planted in the fall have started growth earlier than trees planted in the spring while fully dormant, but none have been planted after growth had started.

Halma (439) reports an interesting study of new root formation with the sour orange stock of Navel orange and Lisbon lemon trees. Roots were cut every six weeks throughout the year, and new root formation observed through a piece of plate glass over the root. There seemed to be root growth only during the period from May to about October. From roots pruned in May, new root formation began at once, but from those pruned earlier it did not begin until May. He says that May is generally considered the best time to transplant citrus trees in California, and he thinks the reason may be that trees planted at that time are more quickly supported by new roots than trees planted before some growth has started. As to whether the explanation of this behavior is to be found in the soil temperature, or in some nutritional condition during California winters, we seem to have no conclusive information.

Summary. Pruning the roots at planting has no beneficial effect and a considerable amount of pruning may be harmful. Smoothing the rough end of the roots is not beneficial; and twisting or bending of the roots does not seem to be harmful, provided roots are not twisted around or bent across each other. Sometimes trees recover better from transplanting when planted in small holes with the soil rammed very firmly, though, if the trees are set while the soil is wet, great firmness may be very harmful; and in some soils it is slightly harmful, or at least not beneficial, even though the planting be done while the soil is in good tilth. Ramming the soil in large holes may always be harmful. Very deep planting is injurious except with plants like the Paradise apple, the currant, and the gooseberry that readily form roots on the stem. With these last, deep planting may be beneficial. Digging holes much deeper than the trees are planted, trenching the rows, or dynamiting holes for the trees are practices that, in humid climates, are seldom if ever beneficial, and besides being expensive may be harmful. Trees are not appreciably injured by being held in a nurseryman's storehouse, if the humidity is uniformly high and the temperature can be prevented from falling lower than about 25° F., and from rising above 36° to 38° F. until nearly planting time in spring. In latitudes where there may be some killing of the sapwood in winter, trees left in a storehouse are much more desirable than trees left out of doors. Fall planting is more beneficial at low than at high latitudes and more feasible. Only those trees should be planted in the fall that, in the climate where grown, are in no danger of injury by freezing.

CHAPTER 8

ASCENT AND DISTRIBUTION OF WATER IN THE TREE

We have studied the nature and growth of the roots of trees and the various problems of the fruit grower in his treatment of the roots. The water supply to the leaves, fruits, and growing parts is determined, not alone by the root system, but also by the water conduction system of the trunk, branches, twigs, spurs, and of the leaves or fruits, and by the extent of the evaporating leaf surface. This conducting system, as well as the amount of leaf surface, can be influenced by the treatment of the tree. The grower thus has his problems also as to his treatment of the tree top in its influence on the water supply.

The ascent of water in the tree. A discussion of the water movement in trees, at all critical, would involve such an extensive review of literature concerning plant physiology more than pomology that it does not seem wise to undertake it here, though a brief statement concerning the present condition of our knowledge on this subject seems necessary. The student should accept such a statement with the understanding that able physiologists are not agreed as to the explanation of the movement of water in trees. To one who has observed the phenomenon of "bleeding" in the spring from cut surfaces near the ground, when the water is forced upward from the roots and out through wounds, this "root pressure" may seem an adequate explanation of the ascent of water. But it should be said that not all bleeding results from root pressure, and it is doubtful if bleeding high in the tree ever does. After the foliage is out upon the tree, there is not an upward pressure from below upon the water columns, but in fact there is a negative pressure, a pressure less than that of the atmosphere. If the water were lifted by pressure from below, the air in the water columns would be compressed by the weight of the water above it. As a matter of fact, however, if there is air in the water columns it is in a rarefied condition. Thus, Höhnel (454) has shown that when a stem is severed under mercury the mercury rises rapidly in the vessels. It is also evident that atmospheric pressure, even though there were no resistance to the movement of the water through the xylem, would raise the water only to a small part of the height of tall trees.

Of the other theories proposed to explain this rise of sap, only two may be considered briefly here. One is the theory formulated by Godlewski (435) and others, that the living cells along the tracheæ exert a pumping action by means of a periodic change in permeability of the protoplasmic membrane. Thus if a cell in contact with more than one trachea should draw water into itself, until the protoplasmic membrane was stretched, and if the permeability was reduced on the upper side of the cell, water would be forced out at this weakest point into the upper trachea, the water then moving upward in the trachea instead of downward, because the air pressure in the tracheæ above was less than that in those of lower levels. Dixon (425) suggests that Godlewski's theory is in reality, therefore, based on the assumption that the upward motion of the water is due to a difference in air pressure at the higher and lower levels, and this difference has never been found great enough to explain the rise of sap. The view that the living cells in some way assist in the rise of sap is suggested by the fact that living cells are always found closely associated with the vessels and tracheids. While the theory that they accomplish the rise of sap by means of changes in permeability does not seem to offer a satisfactory explanation, it seems possible that they may in some way aid, at least, in lifting the sap.

The theory that is based upon the most extensive investigations is generally known as the cohesion theory. This assumes that the water is drawn up by means of a force applied at the top of the column. This force is continued downward through the columns by the cohesion of the particles of the water. Ordinarily we do not think of a liquid as possessing an appreciable tensile strength. Experiments, however, indicate that under certain conditions it may. Dixon (425) says "the liquid becomes capable of sustaining and transmitting tensile stresses only when it is adhering completely to a rigid envelope." In this condition the stretching force acts solely against the cohesive force of the liquid. The unenclosed liquid cannot transmit a tensile stress because, unlike a solid, particles of the liquid are free to move around each other. Then any force of compression or tension spends itself in leading to readjustments of form. Dixon shows that even with a column of liquid adhering to a surrounding envelope, the column may break if bubbles, for any reason, form and enlarge in it. Thus, a slight jar administered to the surface of a glass tube containing water under tension will cause such a bubble to form. If it is very small, the surface tension of the liquid around it may prevent its enlarging. Of course, as it enlarges the surface tension forces decrease, and the water column may be entirely separated. However, as suggested above, a column of water of considerable length may be suspended in a glass tube held by the adhesion of the surface particles to the glass, and the cohesion of the particles to each other. This can happen even when atmospheric pressure has been eliminated.

Dixon and others have shown that water in a glass tube and containing dissolved air will sustain a tension of more than fifty atmospheres. Dixon has shown also that the adhesion of water to the walls of the conducting tissue is greater than its adhesion to glass. His work suggests that the sap of trees is somewhat more stable under tension than is pure water.

We have seen that the sap in the water-conducting tissue is capable of sustaining the strain of a large force drawing from the top. And the cells could probably remain turgid with the water columns under rather high tension. By determinations of the freezing point, which indicates the molar concentration of materials in solution in the cell sap, Dixon has shown that the osmotic pressure in the cells of the leaves may be greater than twenty-five atmospheres; and other determinations (62) indicate that the osmotic pressure in the cells of apple leaves may be considerably above twenty-five atmospheres. The distended condition of the protoplasmic membrane is maintained by this osmotic pressure of the dissolved substances. According to this cohesion theory, water, through its own kinetic energy, evaporates from surface leaf cells, and these take water from the cells surrounding the vessels and tracheids. This can be replaced only by drawing water from the tracheids or vessels. This pull, then, on the upper ends of the columns, is transmitted downward by means of the cohesion of the water. Dixon points out that the water in the cells surrounding the conducting channels would be under tension, that is at negative pressure, while the dissolved substance would be at a positive pressure, capable of distending the cell membrane. He has shown experimentally that such a condition can exist.

If the sap in the conduction tissue is capable of sustaining a tension of more than fifty atmospheres, and if the osmotic force in the cells surrounding the vessels in the leaves is nearly that great, is that pull sufficient to lift the water in the tree as rapidly as it is known to move, against the resistance that it must overcome? Of course, to balance a column of water as high as the tallest trees would require a force of a little more than ten atmospheres, and with most trees little more than three or four, while with fruit trees more than one atmosphere would seldom be required. Since, however, the water moves rather rapidly through the conducting channel, it must overcome a considerable resistance. Ewart (426, 427) seemed to find that these resistances are so large that a head of water from six to thirty-three times the height of the tree would be required to force the sap upward as rapidly as it actually moves. Dixon (425) seems to find that Ewart's results are too high, and that with some trees at least, a head of water twice as high as the tree would be sufficient to lift the sap as rapidly as it normally moves through the tree. If this be true, then, even with the tallest known trees, a force larger than twenty atmospheres would seldom be required.

The resistance in the same branch or tree should vary at different times, if there is air in the water columns and the amount varies. Air bubbles of considerable size would, of course, disconnect the tensile water columns. Dixon thinks that the nature of the conducting tissue with its complicated, interweaving, rather short tracheids and vessels, is explained by the purpose it may serve in preventing complete disruption of the water system. Thus, when an air bubble forms in a given tracheid it may enlarge until it completely fills that tracheid, but it does not easily pass through the walls into an adjoining tracheid. The water, however, would be able to move around this air-filled tracheid through adjacent ones, and thus maintain a continuous column. If there were many such air-filled tracheids, or vessels, then the continuous conducting channel would be reduced in size, and the resistance therefore increased; for the more rapidly the water moves through a given channel, the greater will be the resistance it must overcome. One would expect that the largest amount of air would be in the conducting tissue during dry times, and, therefore, that the resistance during such times of greatest water need would be much greater than at ordinary times. Since with our fruit trees, however, the osmotic pressure in the leaf cells, and therefore the tension that may be in the water columns without causing serious wilting, generally amounts to considerably more than twenty atmospheres, it seems probable that the resistance to water movement would seldom be enough to be a determining factor, in so far as the total amount of water supplied to the leaves of the tree is concerned. Further, Bode (389a) offers strong evidence that, at least with herbaceous plants such as the pumpkin vine or *Impatiens*, there are no air bubbles in the vessels; but they are full of water even when the plant is badly wilted.

Shull has suggested that imbibition in the cell may be an important feature in the movement of water. He (518) found with the cocklebur (*Xanthium*), which has a seed coat permeable to water but not to certain substances which may be dissolved in water, that the cell walls of dry seed will take pure water through this membrane from a solution of lithium chloride whose osmotic concentration is estimated to be 965 atmospheres. Of course, as the walls take up water, this imbibitional pull becomes less, being nothing at saturation. The osmotic pull of the material dissolved in the cell sap is also less as the cell approaches complete turgidity. Thus, a cell whose osmotic concentration was equal to but one atmosphere might take water away from one whose osmotic concentration was ten atmospheres, provided the latter was fully distended and the former was not. Shull (519a) thinks that in the movement of water there is always a tendency toward the establishment of equilibrium between the osmotic force in the cell and the force of imbibition; equilibrium between the force of imbibition of adjacent cell walls; and equilibrium between the tension of the water in the vessels and the imbibitional force in the walls. Water is evaporated from the cell wall and thus an imbibitional deficit is created which will be satisfied partly through the taking of water from the cell vacuole and the creation of an osmotic deficit. Water may be taken from adjacent cells by osmosis and imbibition. A deficit in the surface cells or in cells back of the stomata is thus transmitted from cell to cell until those bordering the vessels take water from the vessels, increasing the tension and thus transmitting the deficit downward to the roots; the water under tension in the vessels of the roots taking imbibitional water from the vessel walls which take it from adjacent cells; the water being taken from the soil by imbibition through the cell walls of the root hairs and of other surface root cells. Deficits can be transmitted downward from the leaves rather rapidly because the water under tension in the long vessels and tracheids can take water at once from so many cells.

That the water in the vessels is under tension seems to have been established beyond question by Bode (389a) who pared off layers of the stem until he could see, through the microscope, uninjured vessels. At no time, not even when the plant was badly wilted, were there air bubbles in the vessels; the vessels would shrink, but remain full of water. Yet, when he cut such a stem under mercury, mercury rose in the vessels. Since there was no air in the vessels to be rarefied, the rise of the mercury must have been due to the release of tension. The vessels were probably contracted due to the tenison of the water; and expanded when that tension was released. Further, due to its tension, the water had probably extracted water from the walls of the vessels and adjacent cells. When the column was severed and the tension released, water was probably drawn back into the walls to satisfy the imbibitional deficit; the water thus taken from the vessels being replaced by mercury. As to how great the tension in the vessels may become, it is very difficult to learn. Renner (507, 509), by use of indirect measurements, seemed to find tensions as great as ten to twenty atmospheres. However, Nordhausen (495), by introducing a measured porous resistance between the plant tissue and its source of water, seemed to find that the tension in the vessels is seldom if ever more than two to four atmospheres. It is interesting to note that when he placed one end of this porous cylinder against the sapwood of a tree, the bark having been removed without cutting the sapwood, water would be drawn through the porous resistance cylinder about as rapidly as when the resistance was placed in contact with the cut end of vessels. He considers this proof that the force pulling the water through the resistance was supplied by living cells directly rather than by the tissue through water columns under tension. However, we have seen that, if the water columns be under tension, there must be an imbibition deficit in the cell walls and an osmotic deficit in the cell vacuoles, each drawing water by a force about equal to the tension in the adjacent water columns. It seems, therefore, that the water may have been pulled through the resistance by the imbibitional force of the cell walls, and from the walls by the osmotic force of the cells and the tension in the water columns.

The tension in the water columns is due to the pull caused by both imbibitional and osmotic deficits, the osmotic and imbititional pull being approximately equal. However, since the possible imbibitional pull is so much greater than the possible osmotic pull, it is probable that the tension in the water columns at the beginning of wilting will be determined by the osmotic concentration of the cells. The tension in the water columns and the imbibitional deficit in the walls when wilting begins will be greater the greater the concentration of ions and molecules in the cell sap; for, with a greater osmotic concentration, the cell will remain turgid against a greater external pull for its water. While a wilted cell with a low concentration may take water from a turgid cell with a high concentration, a nearly turgid cell with a high sap concentration may take water from even a less nearly turgid cell with a low sap concentration. In other words, with an equal imbibitional deficit and an equal tension in the water columns a cell with a high osmotic concentration should be able to obtain water and remain more nearly turgid than with a cell having a lower osmotic concentration.

Water loss from the leaves. In relation to the water supply of the growing parts, a study of some features of the water loss from the leaves is desirable. It has been shown by Edith Shreve (517) and by Bakke (371) that the maximum transpiration is reached at an earlier hour in the day than is the maximum evaporation rate, as determined by use of atmometers. The rate of water loss from the leaves, then, is not determined entirely by the air conditions that favor a high rate of evaporation from atmometers. Briggs and Shantz (398) have shown that transpiration is not increased by increases in wind velocity to anything like the extent that evaporation from a porous-cup atmometer is increased. On the other hand, to increase in solar radiation transpiration from the leaves responded more markedly than did evaporation from atmometers. In another investigation (397) they find the correlation coefficient of transpiration with radiation to range from .82 to .89, with temperature from

.77 to .86, with wet-bulb depression (air dryness) from .75 to .85. Since the sum of the squares of the coefficients of these causative factors exceeds unity, the authors conclude that there must be intercorrelations among them. If solar radiation is taken as the primary causative factor, then, by these correlation coefficients, 66 to 77 per cent of the transpiration on clear days at Akron, Colorado, is determined by the radiation intensity. Since the leaf is of a dark color that absorbs heat rays, it would seem probable that in direct sunlight the leaf temperature might, in spite of the cooling effect of evaporation, be higher than the air temperature. Edith Shreve and others have shown that this is true with some plants, but there is evidence that some plants maintain, in sunlight, a leaf temperature lower than that of the air. If the temperature of the leaf should be above that of the air, then the vapor pressure within the leaf would be markedly greater than that outside, and there should be outward movement of moisture, even when the air is nearly saturated. Theoretically, then, with some plants at least, we should expect the rate of transpiration to be influenced by the intensity of sunlight more than by any other factor. Livingston (473) has shown that this may be true. Trees certainly suffer less from a low soil moisture supply if the humidity of the air is high than if it is low; but sunlight is seldom very intense when air humidity is high.

A study of the moisture percentages in the leaves and twigs seems to give some explanation of the fact that maximum transpiration is reached earlier in the day than maximum evaporation from an atmometer. There seems to be an incipient drying in the leaves by the middle of the day, a condition that would be expected to reduce the rate of transpiration. Livingston and Brown (474), and Edith Shreve (517) have found that under desert conditions the moisture content of the leaves is appreciably lower in the afternoon than in the morning. In fact it begins to decline reasonably early in the morning. The last author found the same to be true of the twigs and branches of *Parkinsonia microphylla*. Lloyd (475) has found with *Fouquieria splendens* that this incipient drying proceeds during the opening period of the stomata and continues after the stomata are as nearly closed as they become. These organs are not, therefore, completely effective in preventing excessive loss of water. Hodgson (453) found incipient drying of the leaves and fruit of *Citrus* in California; Renner (509) has found the same to be true of leaves in a more humid climate. In work done at Ithaca, New York, in a humid climate, all of a number of tests with the leaves of the apple and other fruit trees have shown this reduction in moisture content during clear days; and several determinations have shown reductions in the moisture content of the bark and sapwood of shoots; while a few determinations have shown this with the sapwood of branches three years old. Many more determinations are necessary, however, before we can say how closely incipient drying in the wood follows that in the leaf. Livingston (473) has shown that even when the moisture supply to the roots is unlimited, there may be incipient drying of the leaves on clear days. In other words, it seems that during a clear day even in a humid climate and when the moisture supply in the soil is adequate, the supply of water to the leaves may not be great enough to replace all that is lost by transpiration.

Of course, such incipient drying will be greater when the soil moisture is inadequate. With adequate soil moisture, the limiting factor must be either the absorbing power of the roots or the conducting power of the tree. If the cohesion theory of the ascent of sap is true, it would seem probable that the limiting factor could hardly be the conducting power of the tree. Thus, we have seen that the osmotic force in the leaf is much greater generally than would be required to lift the water as rapidly as it actually moves in the tree. It would seem that conducting power would be a limiting factor only in case of gnarly and slender branches in competition with other branches having better conducting tissue. If the water supply is inadequate and the water columns are under tension, larger quantities may move through the conducting tissues offering the least resistance. That the conducting power of the tree, in the case of our rather low fruit trees, can seldom be the limiting factor as to water supply for the trees as a whole is suggested by the fact that a pear, apple, or peach tree that has had practically all of its sapwood killed by freezing may make excellent growth after a very thin new layer of sapwood has been formed. That the water does not move readily through the dead wood is suggested by the fact that growth is very weak until there is a new layer of sapwood. In other words, a small percentage of the sapwood normally available is sufficient to conduct water through it rapidly enough for the tree to grow well. From this it seems probable that incipient drying in the leaves when the soil water supply is abundant must result from inability of the roots to absorb the water as fast as it is evaporated, rather than from inability of the tree to conduct the water from the roots to the leaves as fast as it is evaporated. However, the cohesion theory has not been completely established; and it may be that the amount of sapwood is not the most important feature in determining the conducting power of the tree. And so we are not in a position to say with certainty that the conductive power of the tree is never an important feature in determining the water supply to the leaf and to the growing points.

Competition for water in the tree. With the supply of water inadequate and the cells of the leaves not fully turgid, it would seem that the tissue with the highest osmotic concentration would have the advantage in obtaining water. If the osmotic concentration in the leaf cells be greater than that in the cells of other tissue, then, although the loss by evaporation is most largely from the leaf cells, the other tissue may come to have the greater water deficit; and it would seem that the reduction in water content in other tissues would occur more quickly on account of the greater pull of the leaf cells. If the cohesion theory of the movement of water is true, then it seems that as water is lost from leaf cells they will take water from the vessels until the tension of the water columns becomes great enough to extract water from cells adjoining the vessels in other parts of the plant. These in turn would extract water from those not directly connected with the vessels. In this way there should be a rapid distribution to other tissues of any incipient drying in the leaves. When water must move from cell to cell, the movement may be less rapid than the movement in the vessels. But the rate of movement should be greater the greater the difference in osmotic concentration between the tissue left and that to which it moves. This should be true whether the movement be from cell to cell, or from cells at one point through water columns under tension to cells at another point.

The osmotic concentration in the leaf is much greater than that in the bark of any part of the tree, as the following list of sap freezing point determinations (62) will show.

TABLE 11. SHOWING THE FREEZING-POINT DEPRESSION IN DEGREES CENTIGRADE OF SAP OF DIFFERENT TISSUES OF THE TREE AT COLUMBIA, MISSOURI.

DATE WHEN TAKEN	KIND OF TREE	SAP FROM BARK OF ROOTS	SAP FROM BARK OF TRUNK	SAP FROM BARK OF MAIN BRANCHES	SAP FROM BARK OF SECONDARY BRANCHES	SAP FROM BARK OF SHOOTS	SAP FROM LEAVES
3- 9-10	Metett apple........	1.391	1.848	1.923	1.738	1.768	..
3-11-10	Pasman apple.......	1.477	2.268	..	1.818	1.698	..
4- 8-11	Reagan apple	1.175	1.590	1.375	1.275	1.270	..
6-10-11	Bloomfield apple.....	1.215	1.370	1.470	1.580	1.930	2.230
6-15-09	Gano apple.........	.927	1.092	1.112	1.132	1.420	2.134
6-23-10	Longevity apple.....	.933	1.133	1.153	1.198	1.343	2.068
7-13-09	Bloomfield apple....	1.265	..	1.695	1.905	2.595	2.540
10-23-09	Lawver apple.......	1.321	1.399	1.557	1.582	1.803	..
7-10-11	Seedling peach......	1.530	1.660	1.740	1.780	2.270	..
8-10-11	Foster peach........	1.285	..	1.825	2.545	2.395	3.015
8-10-11	Foster peach (vigorous)	1.245	..	1.825	2.240	2.185	2.840
9-17-12	Lily of Kent apple...	1.105	1.415	1.292	1.361	1.488	1.955
12- 2-12	Lily of Kent apple...	1.420	1.930	1.665	1.500	2.000	..

Determinations in New York have shown as great differences or greater. Thus the following set of determinations taken at Ithaca, New York, on July 26, 1915, is typical of a number of sets of determinations:

TABLE 12. SHOWING THE FREEZING-POINT DEPRESSION, IN DEGREES CENTIGRADE, OF SAP OF TREES AT ITHACA, NEW YORK

KIND OF TREE	SHOOT BARK SAP	LEAF SAP
Baldwin apple...............	1.451	1.826
Rhode Island Greening apple..	1.195	1.690
Tompkins King apple.........	1.206	1.769

Bark sap only was taken because there was not available apparatus with which the pressure could be made great enough to extract water from sapwood. Sap expressed from the bark generally has a considerably higher osmotic concentration than that expressed from sapwood. Thus, Professor J. P. Bennett found, with Bartlett pear tree tissue taken October 20, 1924, at Berkeley, California, the depression of sap expressed from medium roots, bark 0.88°, sapwood 0.69°; larger roots, bark 0.98°, sapwood 0.81°; trunk, bark 1.16°, sapwood 0.50°; branches three years old, bark 1.31°, sapwood 0.65°; branches two years old, bark 1.31°, sapwood 0.70°; terminal half of shoots, bark 1.51°, sapwood 0.96° C. His determinations at other times with pear trees and with apricot trees gave the same results as to the greater concentration of sap from the bark, the difference being greater above than below the surface of the soil. It does not necessarily follow that concentration in the living cells of the sapwood is less than that in the living cells of the bark. Much of the water extracted from sapwood is probably from the non-living vessels and tracheids, in which the concentration probably tends to be much below that of the living cells. It seems probable that sap expressed from the bark gives the better indication as to the osmotic concentration of the living cells at different levels of the tree.

The data given in Tables 11 and 12 are of the actual freezing points as determined in the laboratory. They can be expressed in atmospheres of possible osmotic pressure by multiplying the depression reading by 22.4 and dividing by 1.86. Thus, with a Bloomfield apple tree at Columbia, Missouri, June 10, 1911, the osmotic concentration of expressed sap was, from root bark 14.7; from trunk bark 16.0; from small branch bark 19.0; from shoot bark 23.2; and from leaves 26.9 atmospheres. At Ithaca, New York, July 26, 1915, the concentration of sap from Baldwin apple tree shoot bark was 17.5 and that of sap from leaves 21.5 atmospheres.

In the summer the osmotic concentration in the bark increases from the roots upward. With the apple tree tissue in Tables 11 and 12, with one exception, the concentration of leaf sap was considerably greater than that of shoot bark sap. And the differences in depression were actually greater than those recorded. The tissues were not killed before the sap was expressed; and Dixon and Atkins and others have shown that the sap expressed from killed leaves has a greater concentration than that from living leaves. That from living leaves does not represent the true concentration in the tissue unless the pressure used is very great. With the pressures used to express the sap for the above data, sap from living leaves of Tompkins King apple ranged from 1.730° to 2.000° C. while from frozen leaves it was from 2.820° to 2.980° C. Yet out of a number of freezings I have never found the concentration of sap expressed from killed bark to be greater than that expressed from living bark. The leaf sap concentration is greater than that of the bark, therefore, by more than the amounts indicated in Tables and 11 and 12; it would seem possible that, before the leaf would lose water enough actually to show wilting, it might draw such quantities from the wood as to leave an inadequate supply for growth. That leaves of detached shoots may pull water from the shoots can easily be proved by coating with paraffin shoots having a small leaf surface left attached and placing them in a position where evaporation is not so rapid as quickly to kill the leaves. It will be seen that the shoot with leaf surface attached will become wrinkled under the paraffin, though under the same conditions a shoot coated with paraffin but with no leaf attached will not. In very sunny climates where at least slight reduction in moisture content might continue through much of the day, it would seem that even when the drying in the leaf is not great enough to cause leaf abscission or even cessation of terminal growth, the slight withdrawal of water by the leaves from the wood might result in a more slender shoot, due to inadequate water supply to the cambium. From observation in a section like that at Ithaca, New York, where there are few days without cloudiness, and in central and south Missouri where the amount of cloudiness in summer is generally small, I should say that twigs of the same variety are generally more slender in the more sunny climate. Miss Fernald (429a) found that early in the growing season, with some species at least, sap expressed from the few inches of tissue, bark and sapwood, at the apex of a growing shoot has a higher concentration than has sap expressed from tissue near the base of the shoot or from the leaves. She thinks that the more rapid growth from apical buds may be due, in part at least, to the advantage thus possessed in competition for water. Later in the season she found the leaves to possess the higher osmotic concentration. It may be that the rather sudden stopping of length growth during periods of water deficit in midsummer can result only when the leaves have come to possess a greater osmotic concentration than that of the growing apex.

That osmotic concentration may be important in the competition for water is suggested by the work of Curtis (92). Generally the terminal buds or those nearest the end of a twig make the most growth. However, when he placed the bases of twigs in sugar solution the basal buds grew best. He thinks that these buds would have the greatest concentration, being nearest the sugar solution, and would, therefore, have an advantage in the competition for water. It would seem that the weak growth of shaded shoots in a tree might be due largely to the fact that in the competition for water they are at a disadvantage because of a lower osmotic concentration, the lower concentration being due to the less active photosynthesis. That the weak growth of shaded shoots is due to their disadvantage in the competition for water is further suggested by the fact that "water sprouts" or "suckers" having favorable connection with the water columns of the larger wood make vigorous growth in these same shaded positions.

The leaves have a much greater osmotic concentration than the fruit. Table 13 gives the results of some freezing-point determinations made at the University of Missouri (62).

TABLE 13. RELATIVE FREEZING-POINT DEPRESSION IN DEGREES CENTIGRADE OF SAPS FROM LEAVES AND FRUITS

KIND OF TREE	DATE TAKEN	DEPRESSION LEAF SAP	DEPRESSION FRUIT SAP
Downing gooseberry	June 2, 1911	1.380	1.005
Columbia gooseberry	June 2, 1911	1.410	.965
Wild Native gooseberry	June 2, 1911	1.530	1.050
Gano apple	July 2, 1911	1.880	1.465
Ben Davis apple	July 27, 1911	1.917	1.230
English Morello cherry (green)	June 5, 1911	2.708	1.425
English Morello cherry (nearly ripe)	June 5, 1911	2.708	2.243
English Morello cherry (ripe)	June 5, 1911	2.708	2.375
Montmorency cherry (green)	June 10, 1913	2.370	1.260
Montmorency cherry (ripe)	June 10, 1913	2.370	1.765
Perfection currant (green)	May 26, 1911	1.130	.930
Perfection currant (nearly ripe)	June 15, 1911	1.130	1.110
Strawberry	June 3, 1911	2.090	.745
Black raspberry	June 26, 1911	1.773	1.108

The tissue was not killed before the sap was expressed, but determinations at Ithaca, New York, indicated that killing the tissue before expressing the sap caused a greater increase in concentration of the expressed sap with leaves than with fruit.

If the water supply should be inadequate through a considerable part of the day, the leaves with their much greater osmotic concentration might pull water away from the fruit; and such a result may be observed. When branches containing leaves and green fruits of any of the varieties named in Table 13, except Perfection currant, were placed in a humid room where evaporation was not rapid enough to kill the leaves at once, the leaves would remain alive and the fruit, even though coated with paraffin, would shrivel to a dried mummy-like appearance. Leaves on branches containing no fruits dried up much more quickly than those on branches with fruit attached. With Sneed peaches after a branch containing fruit had been detached four days the leaves were fresh in appearance while those on a branch with no fruit were badly wilted in fifteen hours. Of course fruits on branches with no leaves did not wilt perceptibly during the four days, whether they were covered with paraffin or not.

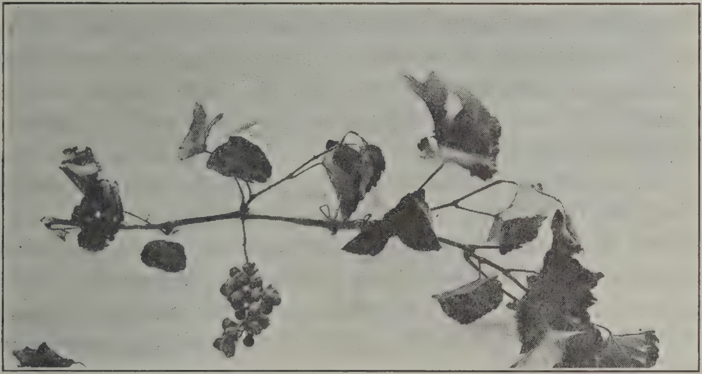

FIGURE 18. Clinton grapes grown at Ithaca, New York, shriveled during a period of high transpiration; leaves uninjured; water supply limited, due to winter injury to sapwood.

Small fruits, unless on the branch in large numbers, would not keep the leaves alive as long as large ones. While green cherries would shrivel from the loss of water, ripe ones under the same conditions would not. From the table it will be seen that the concentration in the ripe cherry fruit is more nearly equal to that in the leaf; but the difference in wilting of the fruit may not be due merely to the difference in sap concentration. It seems possible that if the water can be withdrawn from the fruit by the leaves in case of detached branches, the same might happen to fruit on the trees, at least, during great water deficiency. At Ithaca, New York, I have not found appreciable reduction in moisture content of fruits during the day even when the leaves showed a reduction of three or four per cent in moisture content. There are so few continuously clear days in Ithaca, however, that incipient drying of the leaves seldom prevails during a large part of the day. Whenever the sun is partly hidden by a cloud the leaves quickly become saturated with water. A few instances have come to my attention where, in the less humid climate of Missouri and Arkansas, a large healthy foliage seemed to result in fruit of reduced size. Thus, Mr. Frank Horsfall, formerly of the Missouri State Fruit Experiment Station, reports that during the season of 1901 he advised a man who owned a peach orchard near Mountain Grove, Missouri, to cultivate it well in order to enable the trees to carry a good crop through the drought. The man did this and retained the foliage on his trees. There was a good crop set, but Mr. Horsfall reports that practically none of the fruits became larger than an egg, and many of them shriveled up on the trees. However, in an adjoining orchard, in uncultivated soil many of the leaves fell during early summer, but the fruit became large enough to be of first class and a good crop was harvested. It seems probable that in this case the large foliage had simply kept the water exhausted from the fruit in much the same manner as with the above mentioned fruit on the branches detached from the trees.

Mix (488) has suggested that certain injuries to the tissues of apples called cork or drouth spot may be caused by the rapid withdrawal of water from the fruit by the leaves. Brooks and Fisher (1210) also found drouth spot on apples in the Pacific northwest apparently resulting from sudden and severe drouth with trees that had made a normal or vigorous spring growth. Under such conditions the water must have been taken away by the leaves; for evaporation from the fruit is exceedingly slow. Hodgson (453) found that leaves on detached Navel orange branches will withdraw water from the fruits. He says that it is a practice of California lemon growers quickly to remove from the prunings lemons large enough to be of value, in order to prevent them from becoming flaccid. He seemed to find also an incipient drying of Navel oranges on the tree, the moisture content being slightly lower in the afternoon than in the morning. He does not think evaporation could have reduced the moisture content so much in a few hours; for the stomatal area of the fruit he found very small; and he thinks it probable that the transpiration from a fruit as compared with that from the leaves situated near it is almost negligible. Experience with detached fruits suggests that this is true for deciduous fruits with the possible exception of the strawberry. Orange trees studied by Hodgson were healthy and making good growth. Yet the fruit seemed at times to suffer a water deficit, which seemed to be the cause of the dropping of the young fruits. This dropping is much worse in the interior sections than in the cooler, more humid coastal sections.

Perhaps the most striking examples of the removal of water from fruit by the leaves has been described by Bartholomew (379), who studied an injury to the lemon which he calls internal decline, a collapse of internal tissue usually at the stylar end. It is found least in the more humid Citrus-growing sections of California; and Bartholomew gives rather strong evidence that it is due to removal of water from the fruit by the leaves. He found that lemons on severed branches would lose water much more rapidly than would detached lemons. He says that in a lemon grove in the afternoon, if the temperature is near 100° F., and the humidity about 20 per cent or less, lemons will be found soft to the touch even though the soil moisture is not especially low. The fruit will be turgid in the following morning.

A greater osmotic concentration is not always the determining factor at least in the falling of leaves during periods of water deficits. Thus, Bartholomew tells me that the older leaves on citrus trees have considerably higher osmotic concentration than have younger leaves. Yet during periods of hot dry winds many more of the older than of the younger leaves fall. Of course, it may be that during such drying times, the water deficit is not greater in older than in younger leaves, but that older leaves are the more easily caused to form absciss layers.

This knowledge of the competition in the top of the tree may help to explain the effect of different soils on the size of fruit. It is quite common for fruit in wet soils to be small, though the tree may carry a very healthy foliage. The most plausible explanation of this would seem to be that during early summer when the shoot growth is made, and therefore the size of the foliage is determined, the small root growth possible in a wet soil might supply sufficient water for a good length growth. However, later in the season, when there is more intense sunlight and evaporation is greater, this increased foliage may be more harmful on account of its withdrawal of water than it is beneficial through increased carbohydrate supply.

The possible ability of the leaves to extract water from the fruit may be of importance in interpreting results of fertilizer experiments, particularly with reference to the effect of fertilizers on the size of fruits. Thus, Alderman (550) found the leaf surface of peach trees fertilized with nitrogen four times as great as that of trees receiving no nitrogen.

Transpiration should therefore be greatly increased, and unless the absorbing power of the roots and the conducting power of the wood were proportionately increased, it would seem that, if soil moisture should be low and the sunlight intense, there might come times when transpiration would be so great on account of the greatly increased foliage that the leaves would draw considerable quantities of water from the fruit. Such withdrawal of water was evident on fertilized plats at Brandsville, Missouri (62), during the dry season of 1913. On peach trees that had received nitrate in the spring and had developed a very large foliage, the fruit was perceptibly wilted during very sunny days. This phenomenon was not to be observed on unfertilized trees with their smaller foliage. The fruit on the nitrate plats was the smaller that year even though the number of fruits to the tree was not appreciably different. In comparing the results of fertilizer experiments in different sections this possible ability of an increased foliage to extract water from the fruit when weather conditions favor excessive transpiration should be considered. Thus it is not impossible that, in sections where there is much cloudiness during the time when the fruit is making most growth, the use of nitrates would increase the size of the fruit, unless it should too greatly increase the number, and that, in sunny climates where transpiration is large, the reverse might tend to be true.

The ability of the leaves to withdraw water from the fruit may also influence results in pruning experiments. In dry years in Missouri trees that had been pruned rather severely in the spring bore larger fruit than others. In the orchard referred to previously peach trees that had been pruned severely in 1910 bore, during the summer of 1911, peaches averaging 122 to the bushel, while trees that had been stimulated to vigorous growth by use of nitrates bore peaches averaging 209 to the bushel. Both the pruned trees and those that had received nitrates continued growth later than those that had received neither nitrogen nor severe pruning. On the trees receiving nitrates, however, the leaf surface was greatly increased. Of course, the root growth was probably increased also, but the use of nitrate may, temporarily, increase top growth more than it increases root growth. The tendency for the fruit of these trees to wilt when the sunlight was intense would suggest that the evaporating power had been increased more than the water supplying power. On the other hand, we shall see later that the effect of severe pruning is rather markedly to reduce the leaf surface even though individual leaves are larger. The removal of the old wood should tend also to reduce resistance to water movement. The increased size on the pruned tree, then, seems to have been the result of an increased water supply to the fruit, due to a reduction in the evaporating leaf surface. The root growth, as we shall see, was reduced by the reduction in leaf surface, though not so rapidly but that the water supply to the part of the top left would probably be greater during a large part of the summer.

With pruning as with the use of nitrogen the effect on the size of the fruit will be different for different climates. Where the fruits make most of their growth during a period of high transpiration, the effect of the very large transpiring leaf surface caused by a large nitrogen supply may be to reduce the size of the fruit, while the effect of the reduction in leaf surface, relative to the absorbing root system, caused by pruning will be greatly to increase the size of the fruit. On the other hand, where the fruit makes much of its growth under conditions such that transpiration is not excessive and the soil water supply is abundant the use of nitrogen, where needed, may increase the size of the fruit more than it is increased by pruning.

Storage of water. There is a very large amount of water stored in the trunk of a large tree. The work of Craib (413) suggests that the amount of this storage water may increase after leaf fall. Perhaps with greatly reduced transpiration the imbibition deficit is being supplied. This storage water may be of great service to the tree during times in winter when the part above ground is thawed and losing water slowly, while the soil is still frozen. It may also be of great importance during days of very high transpiration; and a part of the invigorating effect of pruning may be due to the larger mass of water in the trunk and branches in proportion to the evaporating leaf surface of the top. With such trees it should be later in the day before the water deficit would be great enough to inhibit growth of the fruit or of other parts. However, it seems probable that in determining the water supply the size of the root system is of much greater importance than any resistances that develop in the tree.

Summary. By what force the water is drawn upward in the tree, is not known. However, it seems certain that, when the tree is transpiring, the water in the vessels is under tension due to imbibitional and osmotic deficits of adjacent cells in the transpiring part of the tree and that, due to this tension, water is taken from the cells lower in the tree, thus causing an imbibitional deficit in the surface root cells and the extraction of water from the soil. It is not known how important in determining the water supply to the top resistance to water movement through the tree may be. However, from the evidence available it seems probable that it is of much less importance than the moisture supply of the soil, the size of the root system, or the extent of the evaporating leaf surface. At times there unquestionably develops great competition for water among different parts of the top of the tree; and evidence suggests that parts having the greatest osmotic concentration will be in the best position to obtain water. The leaves have much greater osmotic concentration than other tissue and particularly than the fruit. It seems probable that during times of great transpiration, following periods of abundant water supply, when the roots will grow slowly and the leaf surface rapidly, there may develop conditions such that the very large leaf surface is detrimental to the development of large fruits, the leaves during much of the day tending to reduce the moisture supply of the fruit. On account of their greater osmotic concentration they may be able to secure a water supply large enough to keep them healthy when that to the fruit is not adequate for growth. Pruning reduces the leaf surface relative to the size of the root system, while fertilizing with nitrogen increases it. Under such conditions the effect of pruning would be to increase the size of the fruit, while that of heavy fertilization with nitrogen would be to reduce the size of the fruit. The effect on size of fruit of both these practices, then, would be influenced by the soil water supply and by the climatic conditions that influence transpiration.

CHAPTER 9

SOME WATER RESPONSES OF FRUIT PLANTS

THERE is to be found in the literature a considerable amount of discussion of water requirements of plants. In such discussions what is meant is the number of grams of water used to the gram of dry matter produced. The term "water requirement" does not seem to be a happy one. That a plant has transpired a given amount of water does not necessarily imply that it required that much water to make the amount of growth it may have made. In a humid climate or one with a considerable amount of cloudiness the water requirement may be much smaller than in one where weather conditions are favorable for a high transpiration rate. It would be expected that the "water requirement" would be smallest in a climate where the transpiration rate is low, but where the temperature is favorable for the growth of the plant and cultural conditions are optimum. In other words, the "water requirement" will be low when transpiration is low and growth is rapid. Thus, Montgomery and Kiesselbach (488a) found with corn the results shown in Table 14, adapted by Briggs and Shantz (395).

TABLE 14. WATER REQUIREMENT OF CORN AS INFLUENCED BY SOIL FERTILITY

SOIL	WATER REQUIREMENT BASED ON TOTAL DRY MATTER	
	No manure	Manure
Infertile	550±16	350±8
Intermediate	479±11	341±4
Fertile	392± 6	347±6

Widtsoe (542) obtained similar results with the use of fertilizers, combinations with nitrogen reducing the water requirement. Briggs and Shantz (395) quote from Sorauer the results shown in Table 15.

TABLE 15. EFFECT OF DRY AND MOIST AIR ON THE WATER REQUIREMENT OF WOODY PLANTS

PLANTS	DURATION DAYS	MOIST AIR		DRY AIR	
		No. of determinations	Water requirement	No. of determinations	Water requirement
Pyrus communis	39	1	284	1	353
Pyrus Malus	39	3	146±3	2	233±27
Vitis vinifera	39	2	113±8	2	220±47
Ailanthus glandulosa	39	1	497	1	467
Robinia pseudoacacia	39	1	331	1	441
Mean	....	......	274	....	343

Montgomery and Kiesselbach (488a) found a water requirement of 340 for corn growing in a dry greenhouse and 191 for corn growing in a humid greenhouse. Widtsoe (543) has shown that when the water supply is abundant under field conditions the water requirement is much greater than when the soil water supply is more limited. Thus, high soil fertility, high air humidity, or limited soil water supply may reduce the water requirement. Briggs and Shantz (394, 395), giving the results of their own work and that of many others, cite water requirement as low as 212 and as high as 1068. Even with the same plant the variations are very great. It is evident that the "water requirement" calculated in this way gives little or no information as to the amount of soil water necessary to produce a crop of fruit.

Since the amount of water passing through the plant is perhaps twenty times to one thousand times as great as that to be found in the plant, it is evident that succulence of the tissue is no indication as to the water needs of the plant. The mere fact that fruits generally contain a very high percentage of water is no indication as to the amount of soil water required in fruit growing. From the work of Babcock (1192) it seems possible that the amount of metabolic water formed in the fruit during its life may be greater than the amount to be found in it at any time.

Permanent wilting of plants. Briggs and Shantz (393) have used the term "wilting coefficient" to designate that moisture content of the soil, expressed as percentage of the dry weight, at which the leaves of plants growing in it will first undergo a permanent reduction in moisture content; the plant does not die, but will not become turgid unless water is added to the soil. The difference between the actual water content of the soil and the wilting coefficient represents the part of the soil moisture content which is available for plant growth. From studying a rather large number of plants, these workers came to the conclusion that the wilting coefficient for all is so nearly the same that the differences are within the range of experimental error. Of course, the wilting coefficient is different for different soils; that for some coarse sands being less than one per cent and that for some clay loams being a little above sixteen per cent. That for a very compact clay may be as high as thirty per cent.

They seemed to find that the wilting coefficient can be calculated with reasonable accuracy when the hygroscopic coefficient (the percentage of moisture that a dry soil will absorb from a saturated atmosphere) is known. In a number of determinations with soils varying from coarse sand to clay loam the ratio of the hygroscopic coefficient to the wilting coefficient varied from 0.556 to 0.815, the average being 0.68 ± .012. In other words, dividing the hygroscopic coefficient by 0.68 gives approximately the wilting coefficient.

It should be expected that some plants might exert a stronger pull than others in taking water from the soil. However, Shull (518) has shown that as the water content of a soil is reduced the surface force increases very rapidly. In Table 16 are given some of his results.

TABLE 16. RELATION OF MOISTURE CONTENT OF A SOIL TO SURFACE FORCE HOLDING THE WATER

MOISTURE PERCENTAGE	SURFACE FORCE HOLDING THE WATER
18.87 per cent	3.8 atmospheres
18.07 " "	7.6 "
17.93 " "	11.4 "
16.06 " "	22.4 "
14.88 " "	38.0 "
13.16 " "	72.0 "
11.79 " "	130.0 "
9.36 " "	375.0 "

It is evident that doubling the osmotic concentration of the plant might not appreciably influence the wilting coefficient. Thus, with the soil used by Shull, if a plant, having an osmotic concentration of 3.8 atmospheres, could just extract water when the moisture content was 18.87 per cent, one whose osmotic concentration was twice as great could just extract water from that soil when its moisture content was 18.07 per cent. Such small differences in moisture content would generally be within the range of experimental error.

Caldwell (401) seemed to find that the wilting coefficient determined by the formula of Briggs and Shantz will be the true wilting coefficient only when the plant is grown under conditions such that the transpiration rate is nearly uniform. When plants were grown under conditions favoring a very high transpiration rate, the water content at permanent wilting was far above that calculated by the formula given by Briggs and Shantz. In other words, Caldwell seemed to find that the percentage of moisture in the soil when permanent wilting of the plant occurs is higher the higher the transpiration rate. Caldwell thinks that permanent wilting is a resultant of the action of transpiration versus root absorption. Shull (518) seemed to find that at the calculated wilting coefficient the force holding the soil water is less than the osmotic force in most plants; and he thinks that if the wilting coefficient is significant it is because of the slow movement of water from soil particle to soil particle rather than because of inability of the plant to take water from the soil particles.

Alway and his associates (368) found that plants, when adjusted gradually to a low water supply, may remove the water to the hygroscopic coefficient, and even below. Such plants would have the amount of transpiration reduced by gradual loss of leaves. Plants, whose roots were in small soil containers and which were caused, by being watered, to make a succulent growth, with a large leaf-surface, would wilt permanently or even die before reducing the water content to such a low percentage.

Batchelor and Reed (383) found that, late in the summer in Southern California, walnut trees can lower the moisture content of the soil to from .54 to .85 of the hygroscopic coefficient and yet mature the wood normally and suffer no permanent wilting. In a three-year-old peach orchard and a six-year-old apricot orchard the average moisture content of the upper three feet of the soil was .82 of the hygroscopic coefficient. They found in that section, in which the rainfall is all during the winter and spring months, that, regardless of the amount of winter rainfall, the moisture content of unirrigated soils was generally at the hygroscopic point or below by the end of the growing season. The water content below the depth of penetration of winter rains or of irrigation water was at the hygroscopic coefficient or lower about all the time; the water table being about eighty feet below the surface. These workers think that, since during much of the time trees may keep the moisture content of the soil considerably below the wilting coefficient as calculated by the formula of Briggs and Shantz, that formula has no great significance in field studies; the hygroscopic coefficient is the most logical point upon which to base all calculations. If the hygroscopic coefficient of the soil is given, with a statement of the ratio of the moisture content to the hygroscopic coefficient, the moisture condition in the soil can be known rather accurately and in relation to the amount that is available to trees.

Resistance of different kinds to low soil moisture content. Loughridge (476) seemed to find among the different fruits and among other crops differences in ability to withstand a given low soil moisture content. He says that the olive, the apricot, and the peach will do well on less water than will other orchard fruits; one per cent of free water (water content above the hygroscopic coefficient) being sufficient. It should be said, however, that Loughridge made his studies wherever the various fruits were growing in different parts of the State of California; and not all the kinds were growing in the same soil type. Loughridge assumed that the water content in excess of the hygroscopic content was equally available in all soils. Thus, apricot trees growing in soil that was almost pure sand were in good condition when the total moisture content was 1.7 per cent and the hygroscopic moisture content was 0.8 per cent, while apple trees growing in a heavy clay with a moisture content of 12.3 per cent and a hygroscopic moisture content of 10.8 per cent were in poor condition. Considering as available for the trees all water in excess of the hygroscopic content, there was available in the apricot soil 0.9 per cent and in the apple soil 1.5 per cent. However, by the formula of Briggs and Shantz the wilting coefficient of the apricot soil would be 1.18 per cent, while that of the apple soil would be 15.88 per cent. In other words, there was moisture above the wilting coefficient in the apricot soil, while the moisture content of the apple soil was considerably below the wilting coefficient. It is probable that with the apples some of the roots had penetrated to the water level, which he says was thirteen feet deep, and that these were keeping the trees alive. Although the leaves of fruit trees do not wilt permanently when the soil moisture content is at the calculated wilting coefficient, it may be that, if the water content of the soil is that low early in the season when the trees are growing or have but recently ceased growth, the water will be obtained by the tree so slowly that it cannot grow, will drop its leaves early in the summer, and will appear to be in bad condition. Thus, Professor Viehmeyer, of the University of California, tells me that he has observed prune and apricot trees in a soil whose moisture content was at the wilting coefficient. The leaves would seem slightly wilted most of the time, but the trees would ripen a fair crop of fruit. Such trees, however, would probably have been classed by Loughridge as not in good condition. If there is any significance for fruit trees of the wilting coefficient as determined by the formula of Briggs and Shantz, the observations of Loughridge suggest that the apple is as resistant to drought as the other fruits studied by him, unless it be the olive. Further, unless the water table is indicated and the moisture content of all soil into which some roots may penetrate is known, conclusions as to drought resistance of trees not growing in the same field cannot safely be drawn.

I know of no evidence that justifies any very specific statements as to the resistance to drought of the different tree fruits. All are more resistant than most other crops that live throughout the year. The olive, the fig, the almond, and the pistachio are apparently the most resistant; though with some of these, if not all, the fruit drops badly if the moisture supply while the fruit is setting is very low. The sweet cherry is thought by many to be very resistant to drought, but the observations of Loughridge and of others in California suggest that the leaves of this tree are injured by drought when leaves of the other fruits are uninjured. However, such injury to the leaves does not seem greatly to reduce the succeeding crop. In much of California the soil water supply from winter rains has not generally become very low before early summer when sweet cherries ripen. Some of the small fruits, and particularly the strawberry, raspberry, and blackberry, are very strikingly injured by drought, especially during the ripening season and the few weeks preceding, crops, especially of the strawberry, being greatly reduced even when the water supply is adequate for optimum growth of field crops. In this characteristic the small fruits are in striking contrast with the tree fruits which may bear excellent crops in years when the rainfall is so small that those field crops that do not mature early in the summer are almost complete failures.

The kinds that would be most resistant of drought in a section like parts of California, where the water table is always too low for roots to penetrate to it, might not necessarily be the most resistant in a section where the water table comes near the surface every spring. In the latter kind of sections apple or pear roots temporarily below the water table probably would seldom be killed; while roots of peach and cherry trees would be more liable to be killed. Apple and pear roots would, therefore, have access to moisture deeper in the soil than would peach or cherry roots. Certainly in such a section the apple is very resistant of drought; in some years bearing excellent fruit when, due to lack of water, practically all field crops fail. However, in such sections with relatively high water tables nearly all other kinds, except small fruits, may bear excellent crops in years when it is too dry for satisfactory development of most field crops. And, with all kinds of fruits, the trees are almost never injured permanently by drought in a humid section where there is always water in lower levels into which the roots may grow; though, in some years, the fruit may be small.

Even in arid sections where the water table is lower and the summer drought more severe, the trees are seldom killed directly by drought. Usually the moisture supply in the soil is reduced so slowly that some of the leaves fall and the rate of water loss from the tree is reduced to a very low level. However, Batchelor and Reed (382) found English walnut trees killed in early winter, when the normal winter rainfall was delayed and the soil moisture content had been reduced to the hygroscopic coefficient or lower by the time of leaf fall. It is probable that water loss from the twigs of young walnut trees would be greater than that from the twigs of most other fruit trees. As to whether or not, under the same conditions, there would have been killing of trees of other kinds than walnuts, I know of no recorded experience.

However, even if the trees are not killed outright or the twigs killed back by such severe drought when there is little available moisture in the lower levels of the soil, they may be so weakened that they easily succumb to disease. There is generally a rather large amount of loss of trees, of some stone fruits at least, in the years following a severe drought if irrigation water is not available. With mature sweet cherry trees in some sections of California the wood in the tops is often so injured that the best growth comes to be on the lower branches.

Annual rainfall necessary for fruit growing without irrigation. Many features are involved in determining the annual precipitation necessary for the growth of any kind of fruit. Generally in a light gravelly soil the water is more quickly exhausted than in a soil containing more clay or vegetable matter. Naturally, if the precipitation is nearly all in a few heavy rains and the larger part runs off without wetting the soil in the deeper layers, more will be required than if there were better distribution. Probably the greatest penetration from a given precipitation will result from snow; unless it thaws rapidly while the ground underneath is frozen. On the other hand, if the precipitation is in the form of light showers at considerable intervals, it may all be lost from the surface without reaching many of the roots of the trees. Or it may penetrate only to the soil layers where the roots are most abundant and be quickly lost by a very rapid transpiration. It is probably the water deep in the soil where the roots have not penetrated thickly, or in which the roots are killed at least once in two or three years by a high water table, that serves as a reserve to be drawn upon slowly, as the roots gradually penetrate it more completely, and thus to give steadiness to the tree's water supply. For this reason, it is probable that, in sections where the rainfall is abundant in most years and the water table is within a few feet of the surface, trees will make fair growth and bear fruit of normal size when the rainfall in a single year is considerably below that which would be necessary if the precipitation had been low in the preceding years and the soil were very dry to depths greater than the roots would penetrate; unless weather conditions in the dry year should be such as to cause transpiration to be so rapid that the growth of the roots into the new layers of moist soil would not supply water enough to keep the wood and fruit from suffering.

The amount of humidity in the air and particularly the amount of cloudiness will, by influencing transpiration, influence the amount of annual rainfall necessary for the satisfactory ripening of fruit. So, also, will the nature of the seasons and the time of ripening of the fruit. At high latitudes, where the earliest fruits would ripen in mid-summer when transpiration would generally be most rapid, the fruits ripening latest in the season when transpiration would tend to be less rapid might suffer the least from a drought; provided there were plenty of water in lower soil levels into which the roots were gradually penetrating. At lower latitudes, in humid regions, fruits ripening earlier than mid-summer — before there has been long-continued, rapid transpiration and before the soil moisture supply has been greatly depleted — will generally suffer least. The earlier ripening fruits will generally be the more satisfactory for growing without irrigation in sections, like much of California, where transpiration is rapid during a long season, and the precipitation is so small that the water table is usually below a layer of very dry soil through which few, if any, roots penetrate.

Examples of the importance of air humidity and cloudiness as influencing the response of trees to a rather low water supply in the surface two or three feet of soil are often observed at Ithaca, New York, where there may be considerable periods during which there is very little precipitation, yet during which the humidity is high and the sky is slightly cloudy or hazy so that transpiration is low. At such times, even though the soil may be rather dry, tree growth may be good. Thus, during the summer of 1921, at a time when the soil (heavy clay) was dry enough to have large cracks in it, there was such a period favoring very low transpiration, and many trees that, during previous weather favoring high transpiration, had formed the terminal bud, started into a second rather vigorous growth. In that section during the latter part of August and during September and October the sky is often so cloudy and the air so humid that transpiration is very low; and in a number of years when the soil was very dry during late summer the fruit was overgrown and "water-cored" badly, indicating excess water supply to the fruit.

Gardner *et al.* (433a) say that heavy crops of sweet cherries, prunes, and apricots are obtained at The Dalles, Oregon, with an average annual rainfall of but sixteen or seventeen inches. In western New York the average annual rainfall is from twenty-nine to thirty-four inches, while, in another section of New York, fruit does well with an average annual rainfall of twenty-six inches; and it is doubtful if the yield would be increased much by an increased rainfall. Yet, of course, much of this runs off. Probably in sections where transpiration was much greater, such an annual rainfall would be inadequate for high production of fruit.

Whitten (734) has suggested that a very dry year may cause a greater reduction in growth of apple trees during the year following than during the year of the drought. If the weather in late summer should be dry enough to cause defoliation, such a result might possibly be expected, since the products of photosynthesis might be reduced. Or, if the soil in late summer should become too dry for root growth, the following season's growth might be reduced. However, in Missouri, in the spring of 1902, following the severe drought of 1901, trees made an excellent growth except in localities where the drought continued until late in the spring of 1902. Of course, if a drought begins in late summer and continues through the winter and the soil is still very dry after growth has started in spring, small growth may be expected; for, with the apple at least and with some other kinds, growth may be expected to be determined by the water supply to the growing points during spring and early summer. But if growth is severely checked in spring, a large second growth may follow if there is an abundant water supply later. An examination of Whitten's tables suggests that shoot growth has been determined by the water supply of spring and early summer rather than by that of the previous summer.

It has been suggested that, provided the nitrogen supply is adequate, an abundant water supply during one growing season may cause an excessive top growth with reduced root growth during that season and a reduced top growth during the following season; carbohydrates being used for the excessive top growth at the expense of the roots when the nitrogen and water supply to the top are abundant. Further, an excessive rainfall and a high water table during one season may result in the killing of the lower roots and thus in a reduced growth during the following year. The problem of the effect of fluctuations in the water table during the growing season should have more study. Probably many fluctuations in growth could be explained by such a study. Sectional differences in the adaptability of kinds of fruit to soils might also be explained. Thus, the apple does not seem to do as well in heavy clay soils in Missouri as in New York. In Missouri the fruits tend to be very small on trees growing in heavy clay soils. It may be that the heavy rains in early summer cause a rising of the water table and a killing of the lower roots, which result combined with the higher transpiration in late summer may cause the fruit to be small. We have seen, in Chapter 8, that the fruit may have insufficient water even when the supply to the tree is large enough to keep the leaves from falling. Woodbury, Noyes, and Oskamp (736) have shown that in Indiana growth of young trees is much better in years with a large rainfall. Except in exceedingly well aerated soils, it does not follow from these observations that an amount of rainfall as high as that of the years in which the largest top growth was made would cause the greatest growth if there were the same rainfall every year. It is probable that in the wet years top growth was made at the expense of root growth and that growth might be less on the succeeding year even if the rainfall should be as large, the checking being due to the reduction in the root system relative to the top. In other words, the soil water supply that would cause the largest top growth during a single year might be larger than the annual supply that would cause the largest growth during a period of four or five years.

Cultivation to conserve moisture. In some fruit-growing sections, by far the most important benefit from cultivation is through its effect on the supply of available nitrogen. In this chapter only the relation of cultivation to the water supply will be treated.

We are changing our views as to the way in which cultivation conserves moisture. It was formerly thought that water moves to the surface rather rapidly by means of water film connections between the soil particles; the movement being in the direction of greatest curvature of these films; that is, in the direction of the smallest soil moisture content. It was thought, therefore, that the loss of water would be greatly reduced by keeping on the surface a dust mulch, a layer of soil so dry that many of the particles are not connected by moisture films. There is certainly a considerable amount of such upward movement from a free water table. But Viehmeyer, in some unpublished work at the University of California, seems to find that there is very slight movement from a soil containing only capillary water to adjacent soil not so near to capillary saturation. In other words, capillary movement of water seems to be very slow except in soil near a free water table.

Alway (367) and Alway and others (368) found that the water tends to be removed from the soil and particularly from the subsoil most largely by means of transpiration from plants. In semi-arid sections the subsoil twelve feet or more in depth had the water content reduced to about the hygroscopic coefficient apparently by means of deep-rooting legumes and other plants; while, during dry years in humid sections, the water was not appreciably depleted from the subsoil, probably because there were no deep-rooting plants to take it out. Mosier and Gustafson (491) and Lyon (661) found with maize as the crop that there was no difference between the moisture content of a soil with a layer of loose soil kept on the surface by tillage and one with the surface hard but the weeds kept off by scraping. Thompson (528) found the same condition with some vegetable crops. It seems that the primary effect of tillage in conserving soil water is in its preventing the growth of weeds that would remove the water.

However, on sloping fields in sections with very low precipitation, it may be desirable to have the soil freshly worked or mulched during the rainy season, in order that as little as possible of the rainfall may run off the surface. And in all sections cultivation is an important means of conserving moisture, even though the conservation is largely through killing weeds rather than through disrupting capillary movement. Emerson (598) found in Nebraska that young trees under clean tillage made the most growth, and moisture determinations showed that soil moisture was more abundant under clean tillage. Stewart (709) and Woodbury, Noyes, and Oskamp (736) found the most growth made by young trees where the soil moisture supply was largest, whether that moisture was conserved by tillage or by mulching.

Relation of planting distances to resistance to drought. Since the water is lost from the soil primarily through plants, it follows that the planting distances are very important in relation to the water supply. If weeds are prevented from growing in the orchard, nearly all the water loss except that from a few inches of the surface soil is through the trees. If the soil at planting time is wet to a considerable depth, there will generally be moisture for growth as long as there are new areas of soil into which the roots are growing. In California, in sections where there is a winter rainfall of twelve to twenty inches or more, young trees may make excellent growth during the first three or four years in the orchard without irrigation other than watering during part of the first summer after being planted. However, after the trees are large enough for roots to have penetrated all the soil, they begin to suffer from drought. Experience in California indicates that in such a sunny climate with no summer rainfall and with low humidity of the air the rate of transpiration is determined largely by the water supply; and the moisture content of the soil into which the roots have penetrated may be reduced to near the hygroscopic coefficient rather early in the summer, the rate of transpiration then becoming low because there is little water available. During the day there is a water deficit in the tissue. If irrigation water is not available, the only means by which this water deficit can be prevented from becoming too great for satisfactory development of the fruit is for the roots to be constantly growing into soil areas from which the water has not been drawn.

It was shown, in Chapter 4, that trees growing with rather limited, but not extremely low, water supply tend to form root systems that are very large in proportion to the size of the top; and the root systems of trees closely planted may within a few years come to occupy all the soil and so to deplete the water supply early in the summer that they suffer considerable injury during the remainder of the season, the fruit often being of very low quality. In the University orchard at Davis, California, rather close planting was disastrous to unirrigated trees of prune, apricot, and other kinds; even though that soil is a very retentive one and the average winter rainfall is about twenty inches.

Planting the trees rather far apart has long been practiced by orchardists in dry climates where irrigation water is not available. According to Kearney (841) olive orchards are successfully grown in parts of Tunis by planting the trees sixty to eighty feet apart. Of course, the amount of water taken from a given soil area can be reduced also by pruning. Generally, in dry climates, even though the planting distance is large, trees of kinds that live long will become large enough that the roots will penetrate all of the soil, unless root growth is reduced by pruning of the tops. Pruning in relation to root growth and water conservation is discussed in Chapters 15, 16, and 17.

It may be that the moisture supply and the mineral nutrient supply are not always the most important features in determining planting distances. Unquestionably under some conditions shading is an important source of injury from too close planting, though it may seldom be the most important source of injury. Pickering (500) studied planting distances in England. He planted some trees closely and others farther apart, and shaded the trees planted farther apart with screens so adjusted that the shadow on the tree was about the same as that made by adjacent trees in the more closely planted orchard. He seemed to find the closely planted trees dwarfed much more than these shaded trees. This greater dwarfing seemed to be due to the crowding of the roots in the soil. His closely planted trees, however, were only six feet apart; and so his work does not furnish conclusive evidence that root crowding would cause a marked difference in behavior between apple trees planted thirty or thirty-five feet apart and trees planted forty feet apart, or between peach, pear, or plum trees planted twenty feet apart and trees of the same kinds planted twenty-five feet apart.

Relation of intercrops and cover crops to the water supply. In tilled orchards crops are often grown between trees to be ploughed under or to be harvested. These crops may take water away from the soil and check the growth of the trees. Thus, Emerson (599) found some cover-crops strikingly to check the growth of young trees. This checking may be desirable in some localities in order to insure the maturity of the wood of young trees before winter. Further, the fruit on young trees is often overgrown and may, therefore, be of undesirable texture and color and sometimes subject to "bitter pit" or "water core." Reducing the water supply by use of a luxuriant cover-crop may thus improve the quality of fruit on such young trees. An intercrop that is harvested may serve these purposes as well as a cover-crop.

With older trees the cover-crop will be grown primarily for the benefit to the soil as to fertility and physical condition. A nice problem, concerning which we have little or no evidence, is presented here. Thus, if, in sections too cold for a cover-crop to grow in winter or even in late autumn, cultivation continues late into the summer before a cover-crop is sown, so little growth will be made that there will seldom be enough vegetable matter ploughed under appreciably to influence the fertility of the soil. On the other hand, if the cover-crop is sown early, let us say in June, it is possible that, particularly when the trees are bearing a heavy crop, the loss of water from the soil may reduce the size of the fruit. When the trees are large, however, with their large evaporating surfaces and root systems, we cannot say how much influence on the water supply to the fruit this earlier sowing of the cover-crop may have. The roots of the trees, being distributed throughout the soil before the planting of the cover-crop, may, when the precipitation is deficient, so deplete the water supply as to prevent the cover-crop from becoming large enough to use an appreciable amount of water. But even if the water loss through the leaves of the cover-crop and from lack of tillage should be considerable, there might be a compensating benefit to the water supply through a larger amount of humus supplied by the cover-crop. It is well known that the water-holding capacity of a soil rich in humus is much greater than that of a soil low in humus; and, although it seems reasonably certain that, in one year, sowing the cover-crop as early as June must reduce the water supply, we cannot be certain that, after the practice has continued long enough appreciably to increase the humus supply, the water supply is not as large as it would have been if in each year the orchard had been cultivated later and a smaller growth of the cover-crop had followed.

In California, where the winter temperature is suitable for the growth of some plants and where the rainfall is in the winter, the cover-crop is grown at that time. Where the winter rainfall is of such a nature that much of it runs off and where during winter and spring there comes to be an excessive amount of free water in the soil, it is doubtful if the cover-crop greatly reduces the depth to which the winter rainfall penetrates. On the other hand, where the winter rainfall is in rather small showers with sunny weather between, it is probable that a winter cover-crop appreciably reduces the depth of penetration of water during winter.

Of course, unless irrigation water and water from winter rains were both inadequate, the cover-crop would generally be desirable even if it appreciably reduced the water supply; unless there should be available an abundant supply of coarse vegetable matter such as manure. The cover-crop is more important for its effect on the physical condition and the fertility of the soil than for its effect on the water supply, and will be discussed in more detail in Chapters 13 and 14.

Response of Fruit Plants to Irrigation Practices

It is not the purpose here to discuss any of the features or problems in irrigation engineering or in any exhaustive way the problems in soil physics or soil chemistry involved. Only the response of the tree to irrigation practices will be discussed.

In irrigation sections in which the winter rainfall is very slight, serious complications in the chemical nature of the soil often result from the fact that injurious substances which may form are not leached away. In parts of California, after rather heavy applications of sodium nitrate have been made for a number of years, serious injury to citrus trees has resulted; apparently due to the accumulation of sodium in the soil and to its replacing calcium in certain soil compounds. Such injury does not seem to have been observed in sections where the winter rainfall is sufficient to carry the excess of sodium into deep layers of the soil. In some cases injurious substances, such as sodium, can be leached out of the soil by use of large quantities of irrigation water, provided there is an adequate drainage system through which the water carrying the injurious substances can be carried away. On account of the danger of developing alkali soil conditions from material in the water or in the fertilizer used, it is important that, particularly in the lower areas of an irrigation district, adequate drainage facilities be provided.

In sections where mineral nitrates cannot be used and manure is not available, the use of a leguminous cover-crop, such as clover or alfalfa, to supply nitrogen may be necessary. This, if grown in summer, may greatly increase the water requirement. Brown (399) says that for the orchards of the Hood River Valley the use of clover or alfalfa about doubles the irrigation water requirement, particularly if a crop is removed for hay and the mulch on the soil is thus reduced.

Relation of the amount of irrigation water to tree growth. Lewis, Kraus, and Rees (471) and Taylor and Downing (526) found that, in the case of apples, heavy irrigation may markedly increase the growth of trees even while they are bearing a crop; and Batchelor (381) found with peaches that the period of maximum shoot growth corresponds to the period of greatest water supply. Even in the case of the trees receiving irrigation only after July 4th there was about as much growth as where the same amount of water was applied in the same number of irrigations between June 11th and July 30th. Fowler and Lipman (432) have studied the water requirement of young lemon trees. The soil used was one that would be classed as a fine sandy loam. They found that the maximum growth was made where the moisture content was maintained at twenty per cent, based on the water-free soil. However, the trees of best appearance as to color and healthy tone, were grown at slightly lower moisture content. The differences in growth with moisture from sixteen to twenty-two per cent were very slight; but the condition of the tree seemed better with moisture near sixteen per cent. Moisture percentages in excess of the optimum were more seriously injurious than inadequate moisture, unless the wilting point was rather closely approached. There seems then a fairly wide range of moisture content that gives nearly equally good results in so far as the first year of treatment is concerned. It would be of great value if we could know the effects of these different soil moisture percentages on root growth. An abundant water supply might result in the carbohydrates' being used for top growth, when if the water supply were less abundant they would accumulate and move in larger proportion to the roots; and the moisture percentage that would result in the largest top growth during one year only might not result in the largest growth during a longer period.

Thomas (527) found that injuriously high moisture content is rather common in citrus groves of California, in heavy soils at least; particularly where irrigation furrows longer than two hundred and fifty to three hundred feet are used; the injurious water content being at the upper ends of the furrows. In such wet areas growth is reduced, the leaves of the trees becoming somewhat yellow, many falling prematurely. The yield of fruit is often greatly reduced. He suggests for such orchards the use of more distributing pipe-lines so that the furrows can be shortened. He found that with such heavy soils the moisture content can be kept more nearly uniform and the soil more favorable for root growth if the water is applied only when needed as indicated by the soil moisture percentage, or at longer intervals; sixty days rather than thirty. And the method of cultivation influenced the rate of penetration of the water; stirring the soil while wet reducing the rate of penetration. He suggests that a better plan would be to harrow the soil lightly as soon after irrigation as the surface becomes dry enough not to puddle, and to delay more thorough cultivation until the soil is dry enough to be worked deeply.

The difference in results obtained by Batchelor in an exceptionally light gravelly soil and by Thomas in a tenacious soil suggests that not only must the practice be adjusted to different kinds of fruits, but that very different practices may be necessary in different soil types.

Irrigation in relation to fruit-bud formation. It would seem that studies in sections where irrigation is necessary would give the most dependable information as to the effect of an abundant and of a low soil water supply on fruit-bud formation; for not only is the moisture supply more nearly under control, but irrigation probably does not influence the supply of available nitrogen to the extent that it is influenced by tillage (though until we have more information concerning the effect of the soil moisture content on the intake of mineral nutrients we cannot be certain to what extent this last is true). In most of the irrigation studies that have been published specific attention has not been given to the influence of very high or very low water supply on fruit-bud formation; but it is probable that, if heavy irrigation had strikingly reduced or increased fruit-bud formation, that fact would have been mentioned in some of the reports made. Taylor and Downing (526) expected to learn something concerning the effect of varying amounts of irrigation water on fruit-bud formation. However, they expected to estimate the amount of fruit-bud formation from records of the amount of fruit thinned off and harvested; and a killing frost during the second spring of their experiment prevented their getting such records. They found fruit-bud formation in all plats so abundant that no differences could be detected by observation in the orchard during the bloom. It seems probable, therefore, though not certain, that, in very sunny climates, excessive irrigation of trees old enough to bear may not be expected to reduce fruit-bud formation sufficiently to affect the crop.

While the increased wood growth resulting from irrigation generally does not seem to reduce the amount of fruit borne by mature trees, it is highly probable that such increased growth while the tree is young may delay its time of coming into bearing. Thus, Professor C. I. Lewis, in a letter, says concerning irrigated trees in Oregon: "One of the hardest problems we have is to take trees from six to eight years of age and make them fruit, because they become very large and are apt to go entirely to wood." Of course, in some of those valleys the soil is exceptionally deep and rather fertile; further, the excessive pruning practiced there may be chiefly responsible for the delay in fruiting of the young trees. Even if very rapid growth, caused by abundant irrigation should be associated with a delay in the initial fruiting of young trees, it does not follow that such a practice must be unprofitable. The increased size of the tree might result in an increase in the amount of fruit borne a year or two later; great enough more than to offset the amount lost by the delay. For such a delay would probably be small. We have seen that when a tree makes very rapid growth in response to an abundant water and nitrogen supply, top growth and the increase in transpiring leaf surface is relatively more rapid than root growth; and, if the climate is one favorable to rapid transpiration in June and July, in spite of the abundant soil water supply, there may be in the tissue such a water deficit during each day as to check growth and to cause accumulation of carbohydrates or the development of whatever condition in the tissue favors fruit-bud formation.

Apparently the water supply may at times be too low for fruit-bud formation. We have seen, in Chapter 2, that Drinkard (595) and Barss (377a) seemed to find fruit-bud formation reduced on potted trees when the water supply was low. In the Santa Clara Valley of California during September, 1918, there was a rain after the prune crop was harvested and a good setting of fruit-buds for the next year. The growers in that valley thought these fruit-buds were formed after the rain. Since then many have irrigated their orchards about that time; and the practice seems to have resulted in a larger setting of buds. However, it may be that it merely stimulated the growth of some new late shoots on which fruit-buds were set.

Effect of irrigation on the fruit. Taylor and Downing (526) found with apples that plats given very heavy irrigation during the early or vegetative period produced such a leaf growth that the resultant shade tended to reduce color. On the other hand, irrigation late in the season tended to give better color. Color was generally poor when the soil was permitted to become too dry during the period of rapid fruit growth. In experiments by Lewis, Kraus, and Rees (471) in Oregon, where irrigation supplemented inadequate rainfall, the apples on irrigated plats had a brighter, more attractive color than those on unirrigated plats, which had the duller, deeper color. Batchelor (381) found high color associated with late watering in the case of peaches. While there was no appreciable difference in the color of the fruits on plats receiving medium and large quantities of water, the fruit on plats receiving insufficient water was very poorly colored.

Taylor and Downing seemed to find that application of medium quantities of water, the amount advancing toward the ripening period, gave fruit of the best quality. Brooks and Fisher (1210) found that "bitter pit" is generally most serious with apples on trees that have been irrigated heavily late in the season. Heavy irrigation late in the season, following light irrigation, tended markedly to increase that injury. While more was found on the larger apples, the percentage of increase in the amount of "bitter pit" due to excessive late irrigation was about the same for large and for small apples.

With apples Lewis, Kraus, and Rees found in parts of Oregon, where trees will fruit reasonably well under thorough cultivation without irrigation, that irrigation increased the size of the fruit and reduced the percentage of culls. The shape also was changed, irrigated fruit being more elongated and angular. Taylor and Downing found in Idaho that irrigation during the ten weeks before picking time, not including the last two weeks, had a very decided effect in increasing the size of the fruit. Irrigation previous to the beginning of this period of rapid fruit growth had very little influence on the size of the fruit. Batchelor (381), working with peaches in a gravelly soil in Utah, found approximately the same results; that is, water applied early in the season in any amount would not compensate for lack of water during the month before harvest. Thus, when thirty-two or sixty-four inches of water were given in eight applications between June 4th and July 30th no marketable fruit was borne, the peaches being dried into mummies on the trees; while when thirty-one and sixty-two acre-inches were given in eight applications between July 4th and September 1st the yields to the plot were respectively 1100 and 1750 pounds of marketable fruit. In the orchard used by Taylor and Downing, red clover was grown; and this probably would remove nearly as much water as would the trees. The orchard with which Batchelor worked was in a very light gravelly soil. With both these orchards the water supplied even in a heavy irrigation probably would be more quickly taken out of the soil than would be the case with many of the heavy California soils under clean cultivation. With these heavy soils, unless the trees were planted rather closely and were old enough for the roots to have penetrated throughout all the soil in a very thorough manner, it is doubtful if size would have been so strikingly influenced by irrigations at any one time in the development of the fruit. Hendrickson (450) reports that in the excellent and very retentive soil at Davis, California, the size of peaches was not appreciably different whether the irrigation was done early in the season or nearer the time of ripening. It is probably better for a normal growth of the fruit, if there is in the soil enough water for a good, though not excessive, seasonal development of the tree and a steady growth of the fruit. It seems certain that if, in a light gravelly soil such as Batchelor worked with, spring and early summer application of water should be such as to cause the development of a very large foliage and the water should be exhausted from the soil before the fruit had reached nearly full size, the large foliage would be detrimental rather than beneficial to the growth of the fruit; unless there were adequate irrigation to nearly the ripening time. In other words, in such a non-retentive soil not only does the early irrigation not reduce the amount of water necessary during the later development of the fruit, but, because of the large foliage produced by heavy early irrigation, the amount necessary for the later development of the fruit will be greater than if the early irrigation were lighter. In a tenacious retentive soil this would probably not be true.

There is a considerable amount of discussion of the harmful effect of heavy irrigation just before the fruit is ripe on its quality; particularly its sugar content and its firmness of texture, characteristics important in determining its value for shipping or for canning. It is often said that an excessive "swelling up" of the fruit is possible, if there is heavy irrigation when it is nearly full grown. Hendrickson did not seem to find this true with apricots on trees growing in a retentive soil and well supplied with water throughout the season. It may be that the large leaf surface, resulting from the abundant water supply early in the season, would transpire water so rapidly as to prevent an excessive supply to the fruit, even though the soil water supply was abundant. If the soil had been less retentive of moisture and there had been less irrigation early in the season, the leaf surface might have been so much smaller that, with an abundant supply of water applied in the later stages of growth of the fruit, transpiration would not have been rapid enough to prevent such a large water supply to the fruit as to cause it to make a rather succulent development.

Certain injuries, such as cracking of the fruit, may result from a heavy irrigation late in its development, if growth has been checked by lack of water earlier. Hendrickson mentions a prune orchard in the Sacramento Valley of California in which a heavy irrigation in mid-summer, after the fruits had been permitted to suffer for water, caused half of the prunes to crack.

While there is need for more study of the effect of irrigation late in the development of the fruit, the evidence we have suggests that particularly with stone fruits it is important that there be, at all times, a moisture supply sufficient for an unchecked growth.

Jones and Culver (467) have furnished some information concerning the effect of an abundant water supply on the composition of the fruit. They analyzed many specimens taken from irrigation and non-irrigation sections of Idaho; the water supply being the larger to the trees in irrigation sections. There may have been some differences in the fruit due to differences in the climate of the different districts. However, the most striking difference in environment of the trees must have been the difference in water supply. Of the varieties of apples studied, Arkansas Black, Ben Davis, Gano, Jonathan, Rome Beauty, Winter Banana, and Yellow Newtown, the non-irrigated generally had slightly the higher percentages of acids and sugar and considerably the higher percentages of solids insoluble in water. With the stone fruits studied, Bing, Republican, Late Duke, and Napoleon cherries, and Hungarian, Italian, and Agen prunes, sugar, acid, total solids, and solids not soluble in water were considerably higher in the non-irrigated fruit. However, only with Italian and Agen prunes was the reduction in sugar and acid due to irrigation great enough appreciably to reduce the flavor. It may be that with these last two fruits the water supply near harvesting time was greater or transpiration less than in sections of California where prunes are grown. With blackberries, dewberries, loganberries, and red raspberries, fruit grown under irrigation was slightly higher in sugar content but generally slightly lower in acid. In fact, irrigation seemed to influence the composition of these fruits but slightly. With grapes and gooseberries the effect of irrigation resembled that with stone fruits. With the strawberry, irrigation seemed to cause a greater reduction in dry matter, sugar, and acid content than with other fruits.

Time of irrigation. In so far as the tree is concerned, with most deciduous species at least, it is probable that largest growth will be obtained if the water supply is ample during the early growing season. The results of the workers mentioned suggest that the largest fruit will be obtained when the irrigation is heaviest late in the developing period of the fruit, provided it is not too light early in the season; though in some cases caution must be exercised in late irrigation to avoid injuries such as bitter pit and water core of apples and splitting or other injury to stone fruits.

Of course, the time of irrigation will depend upon local conditions. In Arizona, McClatchie (483) found entirely satisfactory results from irrigation in the dormant season only. Under his conditions the water available for irrigation purposes is more nearly adequate at that time, the soil fairly retentive, and the small annual rainfall is in the mid-summer months. In the gravelly soils with which Batchelor worked in Utah, however, it does not seem that dormant irrigation alone in any quantity would give satisfactory results with peaches unless the trees were very far apart. Where the soil is retentive such dormant season irrigation alone might give satisfactory results with early ripening fruits, such as the cherry, the apricot, early peaches, and early plums; though the trees would be kept in better condition where summer irrigation also could be practiced. Batchelor and Reed find that in walnut orchards in Southern California it is possible by means of winter irrigation to get deeper penetration of the water than is ever obtained by irrigation while the trees are in foliage. Water is often more abundant in winter than at other times, and in sections where the water table is very low — below a layer of dry soil — it would seem that such winter irrigation, if not very expensive, might generally be desirable. Autumn or early winter irrigations may prevent such injury as that observed by Batchelor and Reed with walnuts.

Bioletti (389) says that in the season of planting a vineyard the most important irrigation is a very thorough one given before the plants are set. If no crop is grown between the trees, it is probable that a single winter or spring irrigation might give fairly satisfactory results in rather retentive soils with young trees, the roots of which have not nearly penetrated all the soil; for throughout the season the roots would be growing into new soil wet by the dormant irrigation.

Because of the great differences in the nature of soils, in the completeness with which the soil is permeated by roots, and in the requirements of different kinds of fruits, it is evident that there can be no widely applicable rules as to time of irrigation. In so far as possible the trees should be irrigated when they need it, in order to prevent injury to the foliage or checking in the development of the fruit.

Irrigation in humid or semi-humid sections. A considerable number of experiments with irrigation in humid or semi-humid sections have been initiated, the purpose of which was to test the value of irrigation during summer droughts that reduce the size of the fruit. So far as I know, none of value have been completed. Naturally one cannot know when the period of drought is coming, and such an experiment must be conducted through many years in order to include a sufficient number of the droughts. Since every section will be different as to climate, such experiments can have little general value. Perhaps one could more accurately determine the wisdom of irrigation in such sections by learning from the weather records the number of droughts to be expected in a period of years, and comparing the benefit that might be expected from irrigation during such droughts with the cost of maintaining equipment for irrigation. The cost of irrigation during short droughts should also be included, for generally the irrigation would be given before the rain. In other words, many irrigations would be given to be followed so closely by a rain that the irrigation would be of no benefit. Another difficulty in estimating the probable returns from such irrigation would result from the fact that need for irrigation is determined, not alone by the amount of rainfall, but also by the amount of transpiration, which is influenced by clearness of the sky and humidity of the atmosphere.

In the case of valuable small fruit crops overhead irrigation, where the water under pressure is forced out through properly distributed holes in the pipes, is sometimes used. With this system there is large expense due to the rusting out of the pipes, whether they are used or not. It seems that it is only with such valuable fruit crops as strawberries and raspberries, if with any, that irrigation can pay in the eastern part of the United States, even in sections where the annual rainfall is as low as twenty-five to thirty inches.

Summary. The amount of water evaporated by a plant in proportion to pounds of dry matter formed is generally greater when the plant is grown in dry air than when it is grown in humid air, but greater when the soil water supply is abundant than when it is limited, and greater when the mineral nutrient supply in the soil is low than when it is abundant. Most fruit trees show great resistance to drought; perhaps largely because of the great penetration of the roots to all parts of the soil being drawn upon. The annual rainfall of a section is not a dependable indication as to its suitability for fruit growing without irrigation. Much depends upon the distribution of the rainfall and also upon the conditions that influence transpiration. Usually in years of excessive rainfall top growth will be very great and root growth small in proportion. In the following year there is likely to be an early checking of top growth due to an inadequate root system. Injuries to the tissue of the fruit that are visible at picking time or become visible during storage may be caused by inadequate water supply to the fruit or by excessive water supply late in the growing season. The water loss through the tree is much greater than that from the surface of the soil, and where trees are grown without irrigation in a region of low rainfall they should be planted farther apart than usual so as to reduce the amount of water taken from the soil. The water loss may be further reduced by pruning. Cultivation conserves water partly by reducing the evaporation from the soil but more largely by killing weeds. Generally in humid sections it influences the supply of available nitrogen more than it influences the water supply. A cover-crop takes water away from the tree which may or may not be desirable. However, the humus added when a cover-crop is ploughed under increases the water-holding capacity of the soil.

Irrigation brings many problems involving both the movement of water in the soil and the means of supplying mineral nutrients. Methods of applying the water should be such that excessive watering of certain areas may be avoided. The best frequency of irrigation, under equal rainfall and atmospheric conditions, will be determined by the water-holding capacity of the soil. The frequency must be much greater in a light gravelly soil than in a more retentive clay, and there is less danger of injuriously high moisture percentages in the light soils. The moisture content should not be so high that root growth is too greatly reduced. With light soils at least, irrigation during the last four to six weeks before ripening has the greatest influence on the size of the fruit. Excessive irrigation just before ripening may reduce the carrying quality of the fruit and increase the amount of such injury as water core and bitter pit in apples; but it tends to brighten the color of fruit. Heavy irrigation early in the season may cause excessive shade and a reduction in color. Fruit of the best quality seems to result from a medium amount of irrigation.

CHAPTER 10

FRUIT SETTING

The question of pollination is an important one to the fruit and nut grower. With nuts the edible portion is the seed and there must be pollination and seed formation. With fruit the edible portion is the pulpy tissue developed from the pericarp, torus, or other tissues associated with the flower. In most cases, however, these tissues will not grow appreciably except under the stimulus of a developing embryo. In fact failure of the flowers to become pollinated in sufficient numbers constitutes one of the most serious losses to fruit growers — in the northeastern part of the United States perhaps the most serious loss, now that injurious diseases and insects have come to be controlled rather effectively by spraying.

The loss of fruit from imperfect pollination results generally, though not always, from the fact that with many varieties of our fruits fertilization must be with pollen from some other variety. This necessity may result from a number of conditions.

Loss of fruit because pollen is not shed at the time when the pistils are receptive (Dichogamy). One of the simplest examples of this kind of loss is where the pollen is all given off before the pistils are in a receptive condition (protandrous flowers) or after they have passed that condition (protogynous flowers). Thus, Stucky (324) seemed to find that with one group of pecans — the varieties of which may be distinguished by the embryonic catkins' being enclosed in long rather slender bud scales and the catkins' being shielded by long narrow conspicuous bracts — stigmas are in a receptive stage from two to ten days before the staminate flowers shed their pollen. However, pollen in many cases was available earlier on injured twigs. With the other group — characterized by the catkins' being enclosed in shorter broader bud scales and the catkins' being shielded by short inconspicuous bracts — the pollen is generally given off at the time the stigmas of varieties of both groups are receptive. The pollen of both groups is viable, but he infers that the tendency in the first group would be toward self-sterility and in the other toward self-fertility, and that there should be trees from the second group planted in orchards of the first group to give earlier pollen. This first group includes the varieties Appomattox, Atlanta, Bradley, Curtis, Frotscher, Money-maker, Pan-American, President, Russell, Stuart, Van Deman, and Young. Some of the group with earlier maturing pollen are Alley, Beverage Triumph, Centennial, Mobile, Mantura, Nelson, Pabst, Randal, Rome, Jerome, Hobson, and San Saba. Lewis (215) says Persian walnut trees may have imperfect pollination while the trees are young because of the small number of staminate catkins. As to whether or not with the monœcious flowers that characterize most of our nut trees losses are common on account of the lack of pollen at the right time, there seems to be little recorded evidence.

Waugh (346–49) finds with some American plums, which, of course, have hermaphrodite flowers, that, particularly when the temperature is rather low during the opening of the flowers, the stigmas may be receptive and possibly pass the receptive stage before pollen is available, the pistils with the receptive stigmas often projecting through the folded petals. This he found very common with varieties of *Prunus americana.*

Varieties that produce no viable pollen. A few species of our fruits are diœcious, as the papaya, *Carica papaya,* the pistachio nut, and generally the American persimmon, *Diospyros virginiana.* In such cases it is necessary to have some barren staminate trees in the planting.

Most of our cultivated varieties of grapes have true hermaphrodite flowers, but *Vitis rotundifolia* has been generally considered diœcious. However, Reimer and Detjen (289) and Husmann and Dearing (195) have described varieties having self-fertile hermaphrodite flowers; and, according to Detjen (102), it seems possible that a good list of self-fertile varieties of that species may be developed. Beach (39–41) found certain varieties of grapes self-sterile. These were mostly of hybrid origin. Most of these self-sterile varieties would not pollinate other varieties, the pollen being sterile, though there were some exceptions. Most of the varieties with sterile pollen have reflexed stamens. This characterizes also the sterile flowers of *Vitis rotundifolia* (Detjen, 102). Booth (51) found that the pollen of such varieties was irregular in form and generally would not germinate in sugar solution, though some varieties of grapes bear both normal pollen and this irregular form.

Dorsey (105) found that, with the abortive pollen, development seems normal through heterotypic and homœotypic divisions and the division of the microspore nucleus. The sterile pollen results from degeneration processes in the generative nucleus or arrested development previous to mitosis in the microspore nucleus. Such aborted pollen was found also with varieties that produce an abundance of fertile pollen.

Some varieties of strawberries also bear abortive stamens and abortive pollen. Valleau (340) found that disintegration takes place with the strawberry at about the same stage as with the grape, or a little earlier. According to Fletcher (134) the earlier custom seems to have been to grow barren staminate plants to pollinate the imperfect pistillate varieties, and Valleau finds that the wild American species from which the cultivated varieties have been developed are generally diœcious. Gardner (142) found, with the Senator Dunlap strawberry, which normally bears hermaphrodite flowers, that growing the plants in pure sand caused nearly all the stamens to be abortive.

Self-incompatibility. The above examples of self-sterility are from lack of viable pollen available when the pistils are receptive. Abundant proof has been furnished by Waite (343), Fletcher (133), Waugh (346), Lewis and Vincent (216), Gardner (139), Detjen (101), Alderman (19), and Knight (205), Dorsey (108), and others, that viable pollen may be unable to fertilize the ovules of the same variety. This self-incompatibility is by far the most important cause of self-sterility from the standpoint of the orchardist. Knight found with self-incompatible varieties of the apple that, when the pollen of the variety was applied to the pistil, the pollen tube would grow much more slowly than when pollen of another variety was used, always so slowly that it did not reach an ovule before disintegration began. East (113) and East and Park (117) have observed the same phenomenon with other self-incompatible plants. They found with species of *Nicotiana* that the pollen tubes of selfed pistils grow at a uniform or slightly accelerated rate, while those of the crossed pistils, though starting to grow at the same rate as the other, pass down the style at a constantly accelerated rate, indicating that secretions in the style offer a stimulus to the growth of the pollen tube. Dorsey (108) thinks this stimulus can hardly come from the egg, for he finds with *Prunus Besseyi* that the pollen tube grows readily down the styles of pistils with abortive ovules. As to whether or not, with varieties normally self-incompatible, under favorable conditions the pollen tubes may sometimes reach the ovules in time for fertilization, there is no conclusive evidence. However, in some orchards under some climatic conditions, varieties generally self-incompatible may fruit well without the presence of another variety; Stout (321) says that as a rule self-incompatible plants manifest a feeble or partial compatibility throughout the blooming period; and East and Park (116) found with *Nicotiana* that, late in the flowering period and under conditions unfavorable for growth, a few seed will be formed from selfed flowers. They seemed to find that pollen tube growth is accelerated by this condition in the plant; and possibly seed formation results because of this acceleration, the pollen tube reaching the ovules in time for fertilization. Climatic or cultural conditions might with some self-incompatible fruit varieties bring about conditions in the flower similar to that associated with pseudo-fertility in *Nicotiana.* Tufts and Philp (335) found with Bartlett pear in California more nearly complete self-unfruitfulness in foothill orchards than in interior valley or coastal orchards. Perhaps the evidence is not conclusive that this difference is due entirely to a difference in the degree of self-incompatibility. Fruits with few seeds or no seeds may be held better by trees in the interior valleys than by those in the foothills. Lewis and Vincent (216) reported in 1909, and Chittenden (65), from his studies at the Wisley Laboratory in England, reported in 1914, that varieties of apples exhibit varying degrees of self-incompatibility. And we shall see, in Tables 19 and 20, that a large percentage of the varieties of apples and pears studied are not consistently self-compatible or self-incompatible. It may be that the different degrees of self-compatility among varieties is due to difference in the acceleration of the pollen tube as described by East and Park, and that the different degrees of self-compatibility exhibited by the same variety in different seasons in different sections may be due to the influence of some environmental feature upon the rate of pollen tube growth. However, we do not have conclusive evidence that it is not due to something else.

How pollen is carried. With some of our fruits, and probably with nearly all or all of them, when a variety is self-sterile the pollen from another variety must be carried by insects. Waugh (348), by use of slides coated with vaseline, and Lewis and Vincent (216), by placing microscope slides coated with glycerine at different distances from apple trees and counting the pollen grains caught, found that the pollen is carried but very small distances by wind; and F. Chittendon (Hooper, 184), by hanging up pieces of glass painted with vaseline, found the same for other fruits. Lewis and Vincent emasculated and removed the petals from fifteen hundred blossoms — all that were on a seven-year-old apple tree — and only five set fruit, although the tree was only twenty feet from another that bloomed profusely.

Hendrickson (174) found that insects may be necessary for the application of the pollen even of some self-fertile varieties. When he covered an Agen prune tree with a mosquito-bar tent, thus excluding insects, very little fruit was set, though, when the tree was covered with mosquito-bar enclosing a hive of bees, the percentage of flowers to set was very high, higher than normal for exposed blossoms. Overholser in some unpublished data found that Yellow Newtown, a partly self-fertile variety of apples, will set very few fruits when insects are prevented from visiting the flowers. How general this need for insect application of pollen of self-fertile varieties may be we do not know. Of course, we know that varieties whose flowers set well in bags do not need such insect activity. Certainly few varieties of peaches or sour cherries would have such need.

Since the pollen generally must be carried by insects, it is important to know what insects are involved. There has been very little study concerning this, but some observations that have been made indicate that bees are the insects that visit the flowers in the greatest numbers. On the other hand, Rawes (284) found apple flowers in England visited in much larger numbers by several other insect species than by bees. Of course, different insects may be the principal pollen-carriers in different regions. Sax (299) seemed to find the bumblebee an important pollen-carrier in the apple orchards of Maine. Husmann and Dearing (195) found a fly and a small beetle active in carrying pollen among *Vitis rotundifolia* flowers. Alderman (19), Auchter (30a), Hendrickson (173), Overholser (unpublished), and others have shown that, at least under some conditions, the placing of bees in an orchard will increase the percentage of flowers setting fruit, even in regions where there is a considerable bee-keeping industry. Naturally, the nearer the tree is to the beehive, the more of its flowers will be visited. However, there may be sections where there are enough bees or other pollen-carrying insects to cause adequate pollination.

Distance pollen may be carried. Insects may visit a tree carrying pollen from another tree a considerable distance away, the number of such visits depending upon the number of insects that are active. It is, therefore, not easy to tell by casual field observations whether or not a variety is self-sterile. Thus, when the weather is warm at blooming time and insects very active, they may carry the pollen in sufficient quantities through rather great distances; and rather large blocks of a single variety may set good crops in such years. It is when the weather at blooming time is unfavorable for insect work that the crops should be influenced by the lack of adjacent trees of another variety. Often in a year when the weather is rather cold at blooming time, in a large orchard mostly of one variety the crop is observed to be much greater on trees around a tree of some other variety. On the other hand, when the weather at blooming time is so cold that no insects are working, trees of self-sterile varieties may not set even in a mixed orchard. Growers say that in unfavorable years for insect work the Ben Davis apple tree will show lessened yield when it is about one hundred and fifty feet from another variety. Of course, in favorable years the pollen will be carried in sufficient quantities much greater distances; but it is the unfavorable year that determines the maximum distance that trees should be from a source of pollen.

It seems, then, that a greater width than two hundred and fifty or three hundred feet for blocks of self-sterile varieties is undesirable even for the apple, pear, or plum. It seems probable that with cherries which, on account of the smallness of the fruit, need a greater percentage of pollination than with the apple or the plum, the maximum distance of a tree from a variety bearing pollen that will fertilize its flowers should be less than one hundred and fifty feet. With strawberries about every third row should be of a pollen-bearing variety.

Cross-incompatibility. There is some evidence that varieties may be inter-sterile; that is, not all varieties blooming together may pollinate each other. Thus, Powell (272) and Close (67) seemed to find in Delaware that Paragon, Stayman, Winesap, and Lily of Kent apples are inter-sterile. However, since they had no successful pollinations with other varieties on these that could serve as checks, their results can hardly be regarded as being conclusive. Auchter (29) working in Maryland found Winesap, Stayman, and Arkansas inter-sterile. Arkansas Black and Kinnaird pollen caused fruit to set on Stayman trees. Arkansas Black and Kinnaird are probably members of the Winesap group. Germination tests in sugar solution indicated that a very small percentage of the pollen of Stayman and Arkansas is viable. Auchter pollinated Lawver pistils with pollen from nineteen varieties. Pollen from only four varieties caused any fruit to set; and, of these four, pollen from Wealthy caused 6 per cent of the flowers to set; that from Mann, 3.5 per cent; that from Kinnaird, 3.3 per cent; and that from Arkansas Black, 0.6 per cent. This may suggest that there is a considerable amount of cross-incompatibility among apple varieties; or it may indicate that results with pollination work are so uncertain that numbers of blossoms less than one thousand should never be used. (Thirty-two to 373 blossoms were used in this last experiment.) Lewis and Vincent (216) found Esopus and Newtown apple varieties to set well in Oregon when pollinated by any of a considerable number of varieties. Hooper (183) found evidence suggesting that Cox Orange pistils and Bramley pollen are incompatible, but Bramley pistils and Cox Orange pollen are compatible. He says he used some hundreds of flowers of each kind. That a cross might be more compatible than its reciprocal seems to be in agreement with the view of East, that where there is a high degree of compatibility the pollen grain possesses an enzyme that, by making available organic material in the pistil, accelerates the growth of the pollen tube. The growth rate and its acceleration would not necessarily be the same with a cross and its reciprocal. Detjen (101) found nearly all varieties tested, of both the self-compatible *Rubus flagellaris* and the self-incompatible *Rubus trivialis*, to fertilize successfully the self-sterile varieties of blackberries. In this cross-pollinating work he used only two to five bags; and so, while setting fruit in them may be accepted as evidence of cross-compatibility, failure to set in so few cases would not be conclusive evidence of cross-incompatibility. Tufts (332) and Tufts and Philp (334) studied the leading varieties of almonds grown in California and found that any of these would pollinate any other except in the case of two pairs. I.X.L. and Nonpareil were cross-incompatible, and so were Texas and Languedoc, reciprocal crosses being also incompatible. Hendrickson (175, 177) and Dorsey (108) seemed to find cross-incompatibility among some varieties of plums. Gardener (139) seemed to find that varieties of sweet cherries may be cross-incompatible. With Bing, Lambert, and Napoleon, the three leading varieties of the Pacific Coast, none seemed able to pollinate either of the others. Hendrickson (177) found the Japanese plum varieties Formosa and Gaviota cross-incompatible. The different fruits will be discussed as to cross-compatibility among leading varieties in the next chapter.

Relation of the weather to fruit setting. Hedrick (1028) has stressed the great loss to New York fruit growers, on account of unfavorable weather at blooming time. In that State the loss is due much less to freezing temperatures that kill the flowers than to cold or rainy weather that interferes with pollination or fertilization. Dorsey (107) found with the plum in Minnesota that the loss from unfavorable weather at blooming time is rather large. Contrary to opinions expressed by some authors, he found injury to the pollen from low temperature or from rain to be small. The pollen is very resistant to low temperature and when the anthers are wet they at once close and thus protect the pollen from rain. Further, the pollen is not easily injured by rain; and he finds that it is not easily washed from the stigmas. He seemed to find that the loss from rainy weather may result from its interference with the activities of insects or from its delaying the growth of the pollen tube to such an extent that it is injured by the drying out or abscission of a part of the style. Knight (205), we have seen, found with self-sterile varieties a marked difference between the rate of growth of selfed pollen tubes and the tubes from pollen of another variety, and that low temperature greatly reduces the rate of growth. At a moderate temperature (exact temperature not given), Rome Beauty pollen required 91 to 120 hours to traverse the Rome Beauty style, while pollen of Jonathan would traverse the Rome Beauty style in 48 hours. However, at a temperature of 91° F. Rome Beauty pollen would traverse the Rome Beauty style in 24 hours. It seems possible that such a temperature effect may be responsible for occasional self-fertility of varieties that seem generally self-incompatible.

Parthenocarpic and other seedless fruit. Pollination or even fertilization of the ovules does not alone determine the setting of fruit. Many of the fruits that fall contain seed. On the other hand, fruits may set parthenocarpically; that is, without fertilization. This is true of Washington Navel and Satsuma oranges and of some varieties of figs. Ewart (123–25) has found that a few varieties of pears quite commonly set seedless fruit parthenocarpically; and Whipple (355) found the same in Montana. Thus, when the ends of the pistils of apple and pear buds were killed by winter freezing, fruit was set parthenocarpically. This setting sometimes occurred even when the pistils had been killed nearly to the ovaries. In many cases, fruit that has set parthenocarpically is quite different from the fruit containing seed. Waite (343) found that self-pollinated pears of partially self-incompatible varieties had fewer seeds than those from the cross-pollinated flowers, and sometimes the fruit was without seed. Fruits with few seeds or none were smaller and of different form from the others. They also tended to mature later. Fletcher (133) found both Bartlett and Kieffer pear fruits from self-pollinated flowers smaller than those from cross-pollinated blossoms. Ewart (123–25) seemed to find that the parthenocarpic fruit is at a disadvantage on the tree in competition with fruits that have the stimulus of a developing embryo. Müller-Thurgau (246) found that seedless grapes would set if the shoot was ringed back of the bloom cluster about eight days before the flowers opened, thus increasing the organic food concentration at the bloom cluster. The sting of plant lice may cause apple flowers to set fruit parthenocarpically. Such fruits hold on to the spur very tenaciously, but are generally small and of a different texture and flavor from that of normal fruits of the variety.

Some varieties do not form seed and yet require pollination before the fruit will develop; that is, the stimulus of the pollen tube growing in the pistil may be required even though the ovules may not be fertilized or may abort if fertilized. Thus, having examined many fruits, I have never seen kernels in such early varieties of peaches as the Sneed, though they require pollination; at least the emasculated blossoms in bags apparently never set fruit. Müller-Thurgau (246) seems to find that it requires pollination to cause varieties of seedless grapes to set fruit, though he found later that grapes may set without pollination. Stout (322) found that seedless fruits on vines of *Vitis Labrusca* were from flowers with viable pollen. He suggests that, with these, seedlessness results from weak "femaleness." Miss Sutton (327) found seedless fruits of Oldenburg apple setting from selfed pistils. Oldenburg apples are often without seed; but as to whether these fruits are set without the stimulation caused by the growth of the pollen tube at least part of the way down the pistil, we cannot say. Of course, if a variety sets fruit without pollination, that characteristic may be as desirable as self-fertility. It seems possible, however, that a variety may possess the ability to set parthenocarpically, but to so slight an extent that the fruit may be more liable to drop under the influence of unfavorable weather conditions or cultural methods.

Many varieties of the Japanese persimmons, *Diospyros Kaki*, will set seedless fruit. Hume (192) has found that with some varieties, though not with all, the nature of the flesh of seedless fruits is very different from that of fruits of the same variety having seeds; the seedy specimens being smaller, ripening earlier, and generally having darker and more coarsely grained flesh that is strikingly different in flavor. This influence of seeds on the nature of the fruit does not involve the effect of pollen of one variety as compared with that of another, but merely the effect of fertilization, and the resultant seed-bearing, as compared with no fertilization. Lewis and Vincent (216), however, thought they observed an influence of the kind of pollen used on the color of Esopus apples, pollen of light-colored varieties reducing the red color of Esopus and that from dark-colored varieties like Arkansas Black increasing it. However, Wicks (359), as a result of a considerable amount of work, could observe no influence of the pollen used on the color of the resulting fruits. It does not seem that any would be expected.

The Abscission of Flowers and Fruits

The fertilization of the ovaries of a flower does not insure the setting of a fruit that will ripen. Many fruits with fertilized ovules fall. Dorsey (108) says that the flowers or fruits of the plum drop in three waves. The first is at blooming time or immediately afterward, and is due to the abortion of the pistil. The second is two weeks after the bloom or a little later and is due to lack of fertilization of the ovules. The third or "June drop" is about two weeks after the second drop. The ovules of fruits in this drop have been fertilized, but for some reason development has stopped. With other fruits, particularly apples and pears, some of the flowers fall without any apparent development of the fruit, and some after slight development, this all occurring rather soon after the petals fall; according to Heinicke (166), within from one to three or four weeks. In late June or early July in New York there occurs another falling of fruits that have gone farther in their development. These droppings of flowers or fruits occur earlier at lower latitudes depending upon the blooming time and the temperature following. The percentage of the flowers that Heinicke found to fall during each of these periods is shown in Table 17.

TABLE 17. SHOWING THE PERCENTAGE OF FLOWERS OR FRUIT TO FALL AT EACH ABSCISSION PERIOD

VARIETY	NUMBER OF FLOWERS	PERCENTAGE OF BLOSSOMS THAT FELL		PERCENTAGE THAT SET
		First drop	Second drop	
Westfield	281	2.5	80.8	16.7
Maiden Blush	281	32.0	44.8	23.1
Tompkins King	557	74.7	6.8	18.5
Fallawater	252	76.2	4.0	19.8
Rhode Island Greening	154	75.3	5.2	19.5
Baldwin	258	78.7	3.5	17.8

This suggests that generally when the first drop is heavy the "June drop" is light, and when the first drop is light the "June drop" is likely to be heavy. Often, with a tree that blooms very heavily the percentage of flowers that set fruit is small; even the total number set may be smaller than the number set from a very light bloom. This is in line with the work of Reed (285), who found with the Lisbon lemon, which has inflorescences with from one to twenty flowers, that a flower in a small inflorescence had a greater chance of developing into a mature fruit than one in a large inflorescence. This is probable because there was less competition among the flowers in the small inflorescence.

With the apple and pear the pistil is compound, containing generally five carpels each with two ovules or rarely more. There are five styles, one to each carpel. There may be but one ovule fertilized to form a seed or there may be ten or more, and it would be expected that the number of seed formed might influence the abscission or holding of the fruit. Heinicke (166) seemed to find that apples of the "June drop" have seeds, but usually fewer than have apples that do not fall. The following table on page 180 gives some of his results.

He gives a considerable amount of data indicating that the number of seeds in a young fruit greatly influences its ability to develop. Thus, of a large number of apples taken in July from spurs that were alike, those with the most seeds were appreciably the larger. Auchter (28) also

Table 18. Number of Seed in Fruits that Fall as Compared with the Number in Fruits that Remain Attached

Variety	Drop Fruit		Attached Fruit	
	Number of fruits	Average number of seeds to the fruit	Number of fruits	Average number of seeds to the fruit
Baldwin	48	3.38	47	4.47
Rhode Island Greening	66	3.51	29	6.43
Maiden Blush	65	3.94	66	6.28

seemed to find a correlation between the total weight of the seeds in the fruit and the weight of the fruit. Heinicke found that when a detached fruit was caused to wilt by leaving a small piece of leaf attached, the side containing no seed would wilt first; and fruits with a full quota of seeds seemed to show a greater sap concentration than fruits with few seeds. It seems that in some way, at least while the fruit is young, the development of the seed serves as a stimulus that favors the development of the fruit, apparently even encouraging the movement of materials to the fruit. He seemed to find that fruit from the central or terminal flower in a cluster has some advantage in its competition with other fruits in the same cluster having the same number of seed, and generally will not require as many seed to cause it to remain attached.

Heinicke found that with an equal number of seeds those fruits on the more vigorous spurs are least likely to fall. Thus, the average weight of 595 spurs that set was 2.55 grams, while the average weight of 760 spurs from which the fruit fell was 1.50 grams. Whether the vigor of the spur was measured by the number of flowers it bore, by the length of the previous season's growth, or by the amount of growth made from an axillary bud on the cluster base, the largest percentage of flowers setting fruit was on the more vigorous spurs. Heinicke also seemed to find that treatments that tend to increase the vigor of growth seem also to increase the percentage of blossoms to set fruit. Thus, pruning a branch rather severely before the bloom seemed to increase the percentage of flowers to set. That it also increased the vigor of the spur was indicated by the fact that it increased the lateral growth from the spur. Thus, from fifty spurs on pruned branches 37.4 per cent of which set fruit, the average weight of lateral growth was 2.68 grams; while, from fifty on unpruned branches 20.4 per cent of which set fruit, the average weight of lateral growth was 1.9 grams. The problem as to just how pruning has increased the ability of the branch to hold its fruit will be discussed a little later. Heinicke (166) and Harvey and Murneek (161) found that, when part or all of the leaves were removed from a flowering spur, the percentage of flowers to set fruit was reduced, the reduction being much greater when all of the leaves were removed.

The absciss layer. A considerable number of workers have studied the abscission of flowers and leaves of plants with which we are not concerned in this chapter. Heinicke (167) studied the abscission of flowers, young fruit and other parts, of the plant with the apple and the pear. When a flower, fruit, or leaf separates from the part to which it is attached, it does so as a result of the formation of an absciss layer. In a humid atmosphere this layer becomes visible to the unaided eye before the blossom falls. It shows as a callus-like ring of tissue projecting slightly. At the beginning the layer may be only about two cell lengths wide, but later, if the flower is not broken off by wind, it may become eight or ten cell lengths wide. These are elongated thin-walled cells. According to Heinicke the elements of the vascular tissue through this layer become stretched like spiral springs, and break leaving fragments in the abscission tissue. Several days after the separation the scar becomes protected by cork.

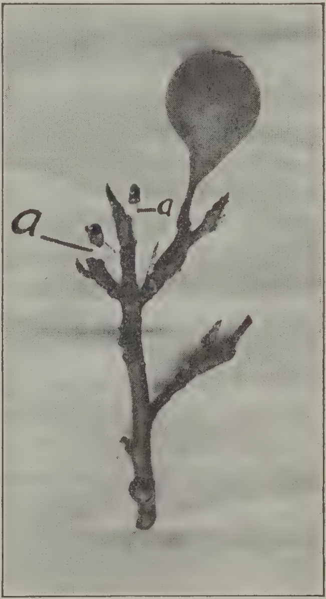

FIGURE 19. Showing at *a* abscission of part of the cluster base of pear spur. (After Heinicke.)

With the apple or the pear, if all of the flowers of a cluster fall, there will be, on the end of the cluster base, a scar for each flower of the cluster. If one flower sets a fruit, however, the scar finally left by the fruit stem may be large enough to obliterate some of the blossom scars. It is often suggested that it is possible, by distinguishing between fruit scars, which cover the end of the cluster base, and the blossom scars, which are smaller and usually about five in number, to tell whether a tree has borne fruit in any year or has merely bloomed without setting fruit. Heinicke finds, however, that if a spur fails to set fruit an absciss layer may cut off the end of the cluster base back to a few millimetres above the attachment of the last leaf. Such an abscission is shown in Figure 19. Such a scar would probably be mistaken for a fruit scar. In drier air this piece of tissue may not be cut off completely by the absciss layer, but only partially, and may remain until it dries and breaks off. If the last leaf and its bud are removed, then an absciss layer will form in the same way just above the next leaf and bud. Dorsey (108) says that, with the plum, when the flowers with aborted pistils (first drop) and those with unfertilized but normal ovules (second drop) fall, the absciss layer is at the base of the pedicel, but with the "June drop" abscission is between the plum and the pedicel as in the case of the ripe fruit.

After the absciss layer begins to form, it can be distinguished microscopically, but according to Heinicke, until formation begins there is no distinguishing feature about the tissue at the base of a pedicel where an absciss layer might form. Seeking a means of stimulating or delaying the formation of the absciss layer, he found that any injury to the pistil may cause this layer to form. When a developing fruit is cut off leaving part or all of the pedicel, an absciss layer is soon formed. However, if water is drawn through this pedicel stub by means of a suction pump, or if water is forced through an excised twig until it exudes from the end of such a pedicel stub, abscission is delayed. It seems possible that in the setting of fruit the influence of vigor in the spur or of an adequate nitrogen or water supply may be explained by their influence on the formation of an absciss layer, and that the differences in the ability of varieties to set fruit parthenocarpically may possibly be due to a variation in the ease with which the formation of an absciss layer is initiated.

Effect of variation in organic and inorganic nutrition on abscission. The vigor of the tree influences the setting of the fruit. The blossoms on young trees making a very vigorous growth seem more liable to fall without setting. It is rather common for young peach trees (trees about three years old) to have a fair bloom and to set little or no fruit in years when older trees set a heavy crop. Powell (272) says that pollination seems to be less successful in the climate of Delaware with young apple trees than with older ones, and Waugh (348) says that with certain varieties of American plums the blossoms of young trees are nearly all defective. Whether or not the dropping of the blossoms of young trees is generally due to defective flowers we cannot say, since there are so few blossoms as compared with the number on old trees. It may be that the percentage to fall is not so much larger than that with older trees as casual observation indicates.

Kraus and Kraybill (211) found that tomato plants, excessively high in nitrogen and low in carbohydrates, made very vigorous growth and dropped nearly all of the bloom without setting fruit. Plants very low in nitrogen and high in carbohydrates — plants very low in vegetative vigor — also dropped most of their blossoms without setting fruit. Under practical orchard conditions there seems to be no danger of getting enough nitrogen into bearing fruit trees to cause the blossoms to fall without setting fruit. At least no experience where nitrogen has had that effect seems to have been reported. And Heinicke (170) applied as much as twenty-five pounds each of sodium nitrate to apple trees twelve years old without reducing the percentage of flowers to set fruit; the soil, too, was one having an abundant supply of available nitrogen.

On the other hand, the blossoms often fall without setting fruit when the trees are growing in a soil very deficient in nitrogen. That a certain nutritional condition in the tree influences abscission is illustrated by the behavior of the San Pedro fig. According to Condit (77) with blossoms of this variety the first crop of the year sets parthenocarpically while the second crop requires pollination. Petri (266) seemed to find with the olive that an insufficient nitrogen supply resulted in an abortion of the ovaries and a dropping of the fruit. He suggests that the large accumulation of the materials resulting from photosynthesis that is most favorable for the initiation of fruit-bud formation may not represent the condition most favorable to the setting of the fruit, and that this accumulation may be caused by lack of nitrogen. In other words, a supply of nitrogen adequate for fruit-bud formation may not be adequate for fruit setting. Lewis and Brown (655) studied means of improving apple trees, in the Hood River Valley, that had come to be of very low vigor; having small pale-green leaves. Lack of nitrogen in the soil was found to be the cause of the low vigor; and they found that, if nitrate was applied about two to three weeks before blooming time, a good crop of fruit would set the same year that the nitrate was applied, while, if the application was delayed until blooming time or later, most of the young fruits would fall. This work was with the Esopus variety, which is at least partially self-compatible, and the Newtown, which is generally highly self-compatible. Reimer (656) seemed to find similar results with Esopus apples and Winter Nelis pears. Ballou (561), working with Ben Davis and Rome Beauty apple trees in the very infertile soils of southeastern Ohio, found, for both trees under cultivation and trees under sod mulch, that when sodium nitrate was applied in the soil about three weeks before the petals fell the percentage of blossoms to set fruit could be greatly increased. Heinicke (166) found a large number of apples on a Tompkins King tree growing in sod to contain an average of 6.1 seeds to the fruit, while a large number from a tree of the same variety growing in cultivated soil contained an average of but 3.8 seeds to the fruit. With both trees opportunity for cross-pollination was good. It has been found that sod in an orchard, generally, reduces the nitrogen supply much more than it reduces the water supply. It seems probable that for the tree in sod the nitrogen supply was so low that all fruits fell except those with a large number of seeds. This effect of nitrogen in increasing the percentage of flowers to set has generally been observed only with trees having a very low nitrogen supply; though Heinicke (170) seemed to find early spring application of nitrogen to increase the percentage of flowers setting fruit on an Arkansas apple tree growing in a tilled soil high in available nitrogen. Cultivated apple trees in that soil seem to make no growth response to applications of nitrogen.

Heinicke found that fruits on vigorous spurs required a smaller number of seeds to prevent their falling than fruits on weaker spurs. It seems probable that the difference in vigor of these spurs might have been caused by differences in the carbohydrate or the nitrogen supply or differences in the carbohydrate nitrogen ratio, or differences in the water supply. He found that pruning back branches during blooming increased the percentage of blossoms to set fruit. Pruning by reducing the number of growing points and the amount of growing cambial area must increase the nitrogen supply to the parts left. By reducing the leaf surface it must also increase the water supply to the parts left. Whether it was increased water supply or increased nitrogen supply that caused the higher percentage of blossoms to set, it is not certain. The trees he used were in cultivation and were growing in a soil in which apple trees would show no growth response to applications of nitrogen. However, it is possible that just at blooming time, when shoot and cambial growth as well as the growth of leaves and flowers are making very great demands upon the nitrogen reserve of the tree, the use of nitrogen may be more rapid than the ability of the tree to conduct it. Under such conditions it is possible that pruning away a part of a branch and thus reducing the use of nitrogen might cause an increased percentage of the flowers to set through an increased nitrogen supply even with trees that will not show a growth response to applications of nitrogen.

Müller-Thurgau (246) found that with certain varieties of grapes (*Vitis vinifera*) fruit will set without fertilization of the ovules. However, if the blossoms are emasculated or if cross-pollination is prevented, generally (246), though not always (248), fruit will not set. With such varieties he found that ringing the canes eight days before the flowers opened prevented the dropping of the fruits. It is common observation, even with varieties that do not set seedless fruit, that the bunches on ringed canes may be more compact; that is, a larger percentage of the blossoms may set fruit that remains until it is ripe. The effect of ringing is generally to increase the accumulation of carbohydrates and often to reduce the supply of nitrogen above the ring. However, checking cane growth by ringing, it seems, might sometimes cause a great enough reduction in the use of nitrogen in new wood and leaf formation that the supply to the young fruit would not be reduced. Heinicke (170) found a greater percentage of the flowers to set fruit on branches ringed about the time the blossoms were beginning to show pink than on adjacent unringed branches carefully chosen as checks. Some of these branches were on trees growing in soil containing an adequate supply of available nitrogen; but some were on weak trees growing in sod with a very low nitrogen supply. With these last either ringing or applying nitrogen before the blooms were open greatly increased the percentage of flowers to set fruit. Ringing increases the amount of carbohydrates relative to nitrogen; while the application of nitrogen should have the reverse effect; yet both treatments increase the setting of fruit. Of course ringing may have other influences. There is the possibility that fruit setting is influenced by some organic nitrogenous compound; that ringing, by preventing this from moving backward, increases the amount available for the young fruit, and that adding nitrogen when the supply is very low also increases the amount of such a substance.

From all of this discussion we can be certain only that with some species under some conditions, from trees just coming into bearing more of the flowers fall without setting fruit than from older trees; that when the nitrogen supply is very low, with apples and pears at least, addition of nitrogen a few weeks before blooming time may very greatly increase the percentage of flowers to set fruit; and that, with trees rather low in nitrogen as well as with trees with an abundant nitrogen supply, ringing — a process that generally increases the carbohydrate supply — causes a rather large increase in the percentage of flowers, above the ring, to set fruit.

The relation of the water supply to abscission. Lloyd (217) and others have given evidence suggesting that the abscission of the flowers of the cotton plant is very generally caused by a water deficit. Coit and Hodgson (71) have shown that in California abscission of the flowers and fruits of the Washington Navel orange is often caused by high transpiration. A study of the yield to the tree in different citrus districts was made during the summer of 1917. Comparing only orchards under like cultural practices, it was found that the yield was smaller the farther the orchard was located away from the coast in sections with low atmospheric humidity and higher temperature. In the Coachella Valley and the southern San Joaquin Valley the yield was only about twenty-five per cent of that in some of the more humid districts. At Corona and Redlands there was a strong dry wind from the north during June 15th, 16th, and 17th, the temperature going as high as 118–120 F.; and as a result nearly all of the Washington Navel oranges fell. It is a rather common experience in some valleys in California that, while the trees of the olive and the almond are very resistant to drought and can be grown without irrigation, often in dry springs nearly all of the fruit will drop.

We have seen that Heinicke (167) found that, when the young fruit is cut off so that a part of the pedicel is left, abscission of this stub occurs in a short time. However, if water is drawn through such a stub by means of suction pump or by placing a drop of sugar solution on the end of it, abscission is delayed. He tried methods of reducing the water supply to flowers by sawing into the sapwood of the branch. He removed rings of bark very carefully just before the flowers were showing pink, then sawed through the younger xylem and replaced the bark which was soon firmly attached to the branch. If the nitrogen moves through phloem and this ring of bark becomes well healed into place before the nitrogen reserve in the branch is too nearly exhausted, then this sawing into the sapwood should reduce only the water supply. Some of the trees were growing in a soil rich in nitrates, and the reserve in the branches must have been so large that, even though the movement of nitrogen was stopped, the nitrogen supply could hardly be reduced to that of branches in an unfertilized sod orchard. In a sod orchard a fair percentage of the blossoms generally set fruit; while with most of these treated branches all of the blossoms or young fruit fell; and with none did more than a very small percentage of the blossoms set fruit; on the untreated branches, a very large percentage of the flowers did so. This suggests strongly that abscission was caused by a water deficit.

We have seen that at Ithaca, New York, Heinicke caused striking increases in the percentage of blossoms to set fruit by pruning back the branches just before the blossoms were opening. In the orchard concerned there is nearly always an abundant supply of soil water in spring and early summer; and the supply of nitrate nitrogen was so large that trees seemed to make no growth response to its application. If the increased percentage of flowers to set fruit on the pruned branches was caused by an increased water supply, then it seems probable that there may be a water deficit to the flowers even when the soil water supply is abundant. From what we have learned in Chapter 8, it seems that such a condition may be possible. Since the leaves have much the higher osmotic concentration, the water deficit should be greater for the young fruits, or the blossoms, than for the leaves. Often during sunny days about blooming time, with young shoots and blossoms, wilting is more apparent than at any other time of the year. This is due as least partly to the fact that they are less woody and, therefore, become more limp under a small water deficit. However, it does not seem impossible that the conducting power of the tree may be very poor when growth first starts. If the living cells of the wood, through their osmotic activity, assist directly or indirectly in raising the water through the xylem of the tree, then the increase in concentration upward in the tree may be very important in the rise of water. We have seen that during the summer, after the accumulation of large quantities of carbohydrates, some of which are moving downward, the sap concentration in the bark of the upper part of the tree is much greater than that of the lower part. About blooming time, however, there is only a rather small difference between the concentration in the bark of the roots and that of the top. It is possible, though not certain, that under such spring conditions the possible conduction of water is much slower than later in the summer, and that, therefore, the water deficit caused by transpiration during sunny days may be greater. If that should be true then a considerable amount of pruning should greatly reduce such water deficits. If in Heinicke's work the increase in the percentage of flowers to set fruit caused by pruning was due to an increase in the water supply to the flowers or young fruit, this benefit from pruning should be very general with varieties of apples and pears that tend to set rather lightly; for the soil water supply in this orchard is always abundant in spring and the transpiration almost certainly far below that for most sections. On the other hand, if the effect of pruning was due to its influence on the nitrogen supply to the parts left, then, in sections where the opening of the blossoms and the development of the young fruit proceed less rapidly, it is probable that in soils rich in nitrogen an optimum supply may be conducted to the flowers or fruits, as fast as it is needed, without the influence of pruning. Of course, it is possible that the benefit from pruning is due to an effect on neither the water nor the nitrogen supply. At any rate, where the nitrogen supply is adequate, with mature bearing trees of varieties of apple and pears that tend to drop the bloom or the young fruit badly, well distributed dormant or late spring pruning seems to be the most promising method of increasing the percentage of the flowers to set fruit.

Some other causes of abscission. With apples, one of the most common causes of abscission is apple scab. Other diseases, no doubt, cause abscission of the flowers and young fruits of some species. Insects, such as codlin moth and curculio cause many young fruits to fall. With apples and to some extent with pears the blossoms may fall as a result of obscure injury from low temperature. Thus, during the springs of 1921 and 1922 at Ithaca, New York, there were rather severe spring freezes during the time when the buds were opening, but before the flowers were showing pink. Sometimes the pistils were apparently unharmed when careful examination would show that tissue in the ovaries was killed. Such flowers generally fell. It was also observed during the spring of 1922 that the stamens were injured more than the pistils, there being almost no pollen formed by some varieties. When the freeze comes after the fruit has set, the seed only may be killed. With the peach and the cherry and apparently with most stone fruits such killing of the seed seems always to cause the young fruit to fall, sometimes after turning yellow or red. This is generally true also with apples; but with some varieties of pears the young fruit with the seed killed may remain attached and form fruit that is normal except for being seedless.

Spraying in bloom, if a poison is used, may kill the bees visiting the flowers. Where the bee is the most important orchard pollinating insect, killing bees must indirectly influence the setting of fruit in the orchard. Spraying during blooming is thought also to injure the flowers. Beach (Beach and Bailey, 44) found that very small quantities of Bordeaux mixture with an arsenical poison or even of Bordeaux mixture alone in a cane-sugar solution would prevent the growth of the pollen tube. Beach found also in field-spraying experiments that blossoms that were hit by a spray of Bordeaux mixture and an arsenical poison were injured and generally set no fruit. However, neither he nor Bailey found conclusive evidence that the crop of apples was reduced by such spraying. Howard and Horne (189) seemed to find no injury to apricot blossoms from spraying with lime sulphur or Bordeaux mixture while the trees were in bloom.

Summary. The failure of blossoms to set fruit and the abscission of partly developed fruit cause very great loss to fruit growers. Such loss results often, though not always, because the pollen of a variety is not able to bring about fertilization of the ovules of that variety. Some of the types of self-unfruitfulness of varieties are, dichogamy, diœcious flowers, abortive pollen, and self-incompatibility, the last being the most important cause of self-unfruitfulness. Self-incompatibility seems to be due to lack of a condition that accelerates the growth of the pollen tube down a style of the same variety. It seems probable that, under certain conditions of nutrition in the flower and under favorable temperature conditions, selfed flowers of varieties normally self-incompatible may form seed and set fruit. This may explain the fact that large orchards sometimes fruit well, though composed of a single variety that, under some condition, has been found self-incompatible. However, with weather favorable for the activity of insects, pollen enough to cause the setting of fruit may be carried several hundred yards. Wind pollination seems to be of little importance in orchards, pollination being almost entirely by insects, except with the nut trees such as chestnuts, pecans, walnuts and hazel nuts. Even with some self-fertile varieties, insect application of the pollen seems necessary. Varieties of apples, pears, or plums that are sometimes or always self-unfruitful should be alternated with other varieties in strips not more than one hundred and fifty to two hundred feet wide. With self-sterile cherry varieties, the strips should be more narrow, since, due to the smallness of the cherry fruit, pollination of more nearly all of the flowers is necessary for a full crop. With the strawberry, every third row should be of a pollen-bearing variety.

There is a considerable amount of evidence indicating that occasionally varieties are cross-incompatible, though apparently cross-compatibility is the more general condition. Cold or wet weather at blooming time may, in the case of varieties that require insect application of pollen, cause great loss of fruit by reducing the percentage of flowers to be visited by insects carrying pollen. With varieties but partly self-compatible, cold weather at blooming time may cause loss by reducing the rate of growth of the pollen tube. When an orchard is found not to be supplied with compatible pollen good results may follow if, each year until top worked trees or branches begin to bloom, small branches bearing compatible pollen are set in buckets of water distributed throughout the orchard. Some varieties set fruit parthenocarpically; and with some varieties of the Japanese persimmon such seedless fruit is very different in nature from fruits with seeds.

With some fruits seedlessness is apparently not due to lack of fertilization, but to disintegration of the embryo with some, such as early peaches, or of the entire ovule with others, such as seedless grapes. After fertilization has taken place, many of the fruits that fall in what is termed the "June drop" have seed, though with the apple and the pear the average number of seeds to the fruit is smaller than the average number in fruits that ripen, the number of seed in a fruit greatly influencing its ability to hold on until it ripens. The vigor of the spur to which the fruit is attached also influences its ability to hold. Fruits or flowers drop as the result of the formation of an absciss layer. When the nitrogen supply is very low, as with trees in sod, application of available nitrogen two or three weeks before the flowers open may greatly reduce the abscission of young fruits. Ringing branches a short time before the blooms are open will also reduce abscission. Such a reduction follows ringing, whether the ringed branch has a very low supply of nitrogen or an abundant supply. Great water deficit, whether resulting from very high transpiration or from limited water supply, may cause the abscission of nearly all of the fruits. Pruning in spring before the blossoms are open reduces the abscission of young fruits. It is not certain whether this is accomplished through an increase in the nitrogen supply or an increase in the water supply or by some other means.

CHAPTER 11

SELF-STERILITY OF VARIETIES OF THE DIFFERENT KINDS OF FRUITS

While the fruit grower is interested in fundamental studies that may explain the phenomenon of self-sterility and make possible an understanding of the apparent inconsistencies in behavior of varieties, his ultimate interest is in detailed studies of varieties as to self-unfruitfulness so that he may the more wisely choose varieties for his climate, and know whether or not, with the varieties chosen, mixed planting is necessary in order to insure satisfactory setting of fruit. When a variety is self-sterile due to the fact that the flowers bear abortive pollen or are diœcious or dichogamous, the fact is easily established by study of the flowers. From what we have learned, however, it is evident that to determine whether or not a variety is self-incompatible is much more difficult. A study of the nature of the flowers tells us nothing as to self-incompatibility. Actual pollination studies must be made; and with these there is a large experimental error due to the small percentage of flowers that normally set fruit and due to the fact that there seem to be varying degrees of self-incompatibility and that the degree of self-incompatibility may be influenced by environmental conditions. Probably few varieties are self-incompatible to such a degree that they are self-sterile under all enviromental conditions.

Methods of studying for self-incompatibility. The most common method of studying a variety as to self-incompatibility is to cover the unopened blossoms with paper bags. If as large percentages of the flowers set fruit in these bags as with uncovered blossoms, it is safe to conclude that, under the conditions of the experiment, the variety is self-fruitful. On the other hand failure to set in the bags is not always such conclusive evidence that the variety is not self-fruitful. Auchter (29) did not find that any greater percentage of apple blossoms set fruit when he applied the pollen with a brush than when bagged blossoms were unmolested. But we have seen that Hendrickson (173) and others found that insect application of the pollen may sometimes be necessary with some self-fertile varieties of plums. And Overholser (259) found that protected flowers of Green Newtown apples would not set fruit unless the pollen was applied to the pistils by insects or by hand. Similar results were obtained by Peters (264) with Victoria and Reine Claude Violette plums, and Hooper (184) says that gooseberries and currants will set well from pollen of the same variety, yet they will not set without insect visitors. Bagging the flowers may give evidence that the pollen must be applied to the pistils by some such agency as insects, but not necessarily that the variety is self-incompatible. Lewis and Vincent (216) avoided this error by removing the bags at blooming time, hand self-pollinating and replacing the bags. It is of course important to know whether or not a variety will set without insect pollination. Other characteristics being equally satisfactory the most desirable variety is one that does not require insect pollination, since in many years in some sections weather at blooming time may be very unfavorable for insect activity.

Another possible source of error in the bagging method is the physiological influence on the spur or branch enclosed in the bag. Thus, Heinicke (166) found a larger percentage of fruit set in translucent than in opaque bags; though perhaps he did not use enough bags to justify positive conclusions. Where bagging is used the percentage of flowers to set fruit in the bags should always be compared with that of flowers exposed to insect visits; for at times the percentage of blossoms to set fruit is small, due to the physiological condition of the tree as is the case of a very young tree that is just coming into bearing. It would seem possible that more nearly normal condition might be obtained by covering the whole tree with thin cloth stretched over frames. However, Alderman (19) and Vincent (341) seemed to find little difference in the percentage of flowers to set in bags and on trees under frames. The mere covering of flowers is a convenient means of making preliminary studies as to self-incompatibility in a variety because many more flowers can be studied with a small amount of work than can be studied by a method requiring emasculation and hand pollination. And if a fair percentage of the flowers of a variety set fruit when covered with the bags it will not be necessary to study that variety by the more laborious method of hand pollination. However, for the reasons suggested above, workers, before concluding from results with bagging that a variety is self-incompatible, study also blossoms that are emasculated and hand pollinated with pollen of the same variety. The percentage, of course, of those selfed blossoms to set fruits is compared with that of other emasculated blossoms cross-pollinated. Naturally, all such blossoms are emasculated, before any pollen matures, and usually protected from insect visits; however, Sax (299) seemed to obtain consistent results with uncovered emasculated flowers. Insects do not seem to visit flowers from which the petals are removed (Lewis and Vincent, 216). The difficulty with hand pollination is that it is so laborious that generally not enough flowers are used. The necessity for large numbers is due to the large percentage of the flowers that fail to set fruit or of the young fruits that fall even though fertilization takes place. This source of error is as large with hand pollinated flowers as with those merely bagged.

We have seen in the previous chapter that, with apples and pears, a larger percentage of the flowers on vigorous spurs set fruit than of those on weak spurs and that the age of the spur influences the percentage of flowers to set fruit. It is probable that in hand pollination work with these fruits the experimental error can be greatly reduced by selecting spurs of uniform age and vigor.

Much can be learned as to self-compatibility of varieties by a study of their behavior in the orchard, particularly in years when the weather at blooming time is unfavorable for the work of insects. Some varieties, such as the Baldwin apple and most varieties of peaches, apricots, and sour cherries, will generally be found setting well even though planted in large blocks with trees of no other variety intermingled, while others such as the Bartlett pear or the Rhode Island Greening apple growing under such conditions may be found to drop most of their flowers without the setting of fruit or to drop the young fruit. If it were found that most of the dropped fruit contained no seed then it would seem probable that failure to set fruit was due to self-sterility of some form; and if the variety was known to bear viable pollen that was available when the pistils were receptive then it would be reasonably certain that the self-sterility was due to self-incompatibility. If, on the other hand, it were found that a large percentage of the fallen fruit contained seeds then it would seem probable that the dropping was due to some physiological condition in the tree rather than to self-sterility. In many of the studies no record has been made as to whether or not fruits set, when cross-pollination was prevented, contained seeds; and since fruits may set parthenocarpically — that is without fertilization — it seems better to use the term "self-fruitful" rather than the term "self-fertile."

The apple. Since it is desirable to know whether or not each important variety is self-fruitful and since the experimental error is large and climatic conditions may influence the degree of self-incompatibility of a variety, it seems best to give in tabular form the evidence concerning each important American variety.

Concerning the results shown in Table 19, Lewis and Vincent give the number of bags used with each variety, but not the number of blossoms covered. The percentages given in Table 19 for their work are, therefore, at least six times too large as compared with the work of the others cited;

TABLE 19. SHOWING EVIDENCE AS TO SELF-FRUITFULNESS OF IMPORTANT AMERICAN VARIETIES OF APPLES

VARIETY	WORKERS	LOCALITY	BLOSSOMS COVERED (a) OR COVERED AND SELFED (b)	PERCENTAGE OF BLOSSOMS SETTING FRUIT
Arkansas	Auchter (29)	Maryland	1909 (a)	0.0
"	"	"	543 (b)	0.0
"	Lewis and Vincent (216)	Oregon	100 bags	0.0
Arkansas Black	Auchter	Maryland	2620 (a)	0.0
" "	"	"	228 (b)	0.0
" "	Lewis and Vincent	Oregon	100 bags	0.0
" "	Vincent (341)	Idaho	448 (a)	0.0
Baldwin	Auchter	Maryland	500 (a)	partly self-fruitful
"	Gowen (154)	Maine	40 (b)	12.5
"	Lewis and Vincent	Oregon	200 bags	7.0
"	Morris (244)	Washington	534 (a)	1.48
"	Sutton (327)	England	many	set well
"	Waugh (347)	Vermont	169 (a)	0.6
"	Sax (299)	Maine	1940	0.8
Ben Davis	Gowen	Maine	339	0.0
" "	Lewis and Vincent	Oregon	100 bags	3.0
" "	Morris	Washington	509 (a)	0.19
" "	Vincent	Idaho	708 (a)	1.2
" "	Wicks (359)	Arkansas	472 (b)	2.3
" "	Sax	Maine	1695	0.4
Cox Orange	Auchter	Maryland	500 (a)	self-fruitful
" "	Chittenden (65)	England	366 (a)	3.8
" "	Vincent	Idaho	1277 (a)	3.2
" "	Sutton	England	289	0.0
Delicious	Crandall (84)	Illinois	?	0.0
"	Morris	Washington	530 (a)	0.0
"	Vincent	Idaho	231 (a)	0.0
Early Harvest	Auchter	Maryland	500 (a)	self-fruitful
" "	Crandall	Illinois	?	0.0
" "	Gowen	Maine	13	0.0
" "	Powell (274)	Delaware	408 (a)	5.9
" "	Vincent	Idaho	152 (a)	1.3
Esopus	Lewis and Vincent	Oregon	100 bags	7.0
"	Morris	Washington	1393 (a)	2.60
"	Vincent	Idaho	629 (a)	0.63
"	Waite (344)	New York	? (b)	0.0
"	Waugh	Vermont	86 (a)	1.2
Fameuse	Crandall	Illinois	? (b)	0.0
"	Gorham (148)	Quebec	1662	1.02
"	Waugh	Vermont	223 (b)	0.4
Gano	Auchter	Maryland	1000 (a)	partly self-fruitful
"	"	"	1173 (a)	0.09
"	"	"	607 (b)	0.49
"	Lewis and Vincent	Oregon	50 bags	0.0
"	Logsdail (220)	Ontario	318	0.0
"	Vincent	Idaho	668 (a)	3.6
Gravenstein	Lewis and Vincent	Oregon	50 bags	0.0
"	Morris	Washington	256 (a)	5.1
"	Powell	Delaware	95 (a)	0.0
"	Vincen	Idaho	826 (a)	3.5
Green Newtown	Lewis and Vincent	Oregon	100 bags	66.0
" "	Morris	Washington	503 (a)	0.19
" "	Sutton	England	13	0.0
" "	Vincent	Idaho	580 (a)	3.8

TABLE 19. SHOWING EVIDENCE AS TO SELF-FRUITFULNESS OF IMPORTANT AMERICAN VARIETIES OF APPLES (*continued*)

VARIETY	WORKERS	LOCALITY	BLOSSOMS COVERED (a) OR COVERED AND SELFED (b)	PERCENTAGE OF BLOSSOMS SETTING FRUIT
Grimes Golden	Auchter	Maryland	1000 (a)	self-fruitful
" "	"	"	661 (a)	1.66
" "	"	"	662 (b)	0.15
" "	Lewis and Vincent	Oregon	100 bags	14.00
" "	Morris	Washington	2484 (a)	1.49
" "	Powell	Delaware	135 (a)	0.0
" "	Sutton	England	36 (b)	0.0
" "	Vincent	Idaho	10765 (a)	2.2
" "	Wicks	Arkansas	442 (b)	8.4
Ingram	Auchter	Maryland	500 (a)	self-fruitful
Jefferis	Vincent	Idaho	438 (a)	1.1
Jonathan	Lewis and Vincent	Oregon	200 bags	0.0
"	Morris	Washington	504 (a)	0.0
"	Vincent	Idaho	19081 (a)	2.9
"	Wicks	Arkansas	452 (b)	3.8
Keswick	Chittenden	England	210 (a)	4.8
"	Lewis and Vincent	Oregon	50 bags	80.0
Lawver	Auchter	Maryland	1377 (a)	0.0
"	"	"	1500 (a)	self-unfruitful
"	"	"	257 (b)	0.0
"	Morris	Washington	506 (a)	0.0
McIntosh	Auchter	Maryland	500 (a)	self-unfruitful
"	Crandall	Illinois	? (b)	" "
"	Gorham	Quebec	2510	0.4
"	Gowen	Maine	28 (b)	0.0
"	Logsdail	Ontario	146	0.0
"	Morris	Washington	365 (a)	8.77
"	Vincent	Idaho	228 (a)	0.0
"	Sax	Maine	1025	0.2
Northern Spy	Gowen	Maine	38	2.6
" "	Morris	Washington	556 (a)	0.0
" "	Vincent	Idaho	43 (a)	0.0
" "	Waugh	Vermont	19 (a)	0.0
" "	Sax	Maine	758	0.0
Oldenburg	Auchter	Maryland	1500 (a)	self-unfruitful
"	Chittenden	England	348 (a)	0.3
"	Crandall	Illinois	? (b)	0.0
"	Gowen	Maine	4	25.0?
"	Lewis and Vincent	Oregon	100 bags	5.0
"	Logsdail	Ontario	479	0.0
"	Morris	Washington	253 (a)	11.46
"	Sutton	England	many	20 fruits
"	Vincent	Idaho	381 (a)	19.9
Ralls	Lewis and Vincent	Oregon	100 bags	0.0
Rambo	Lewis and Vincent	Oregon	100 bags	2.0
Red Astrachan	Auchter	Maryland	500 (a)	partly self-fruitful
" "	Crandall	Illinois	? (a)	0.0
" "	Gowen	Maine	4	0.0
" "	Powell	Delaware	200 (a)	6.0
" "	Waugh	Vermont	16 (a)	0.0
Red Canada	Lewis and Vincent	Oregon	50 bags	2.0
" "	Waugh	Vermont	80 (a)	0.0
Red June	Auchter	Maryland	500 (a)	self-unfruitful
" "	Crandall	Illinois	? (b)	0.0
" "	Vincent	Idaho	180 (a)	33.3

TABLE 19. SHOWING EVIDENCE AS TO SELF-FRUITFULNESS OF IMPORTANT AMERICAN VARIETIES OF APPLES (*continued*)

VARIETY	WORKERS	LOCALITY	BLOSSOMS COVERED (a) OR COVERED AND SELFED (b)	PERCENTAGE OF BLOSSOMS SETTING FRUIT
R.I. Greening	Crandall	Illinois	? (b)	0.0
" "	Gowen	Maine	14	0.0
" "	Lewis and Vincent	Oregon	100 bags	0.0
" "	Morris	Washington	566 (a)	3.05
" "	Vincent	Idaho	626 (a)	0.0
" "	Waite	New York	?	self-unfruitful
" "	Waugh	Vermont	703	0.0
" "	Sax	Maine	335	0.0
Ribston	Chittenden	England	162 (a)	3.7
"	Sutton	England	336	2.4
Rome Beauty	Alderman	West Virginia	16826 (b)	0.99
" "	Auchter	Maryland	1000 (a)	self-fruitful
" "	Lewis and Vincent	Oregon	100 bags	0.0
" "	Logsdail	Ontario	166 (a)	0.0
" "	Vincent	Idaho	10326 (a)	4.5
Shiawassee	Lewis and Vincent	Oregon	100 bags	23.0
Shockley	Auchter	Maryland	500 (a)	self-unfruitful
Stark	Auchter	Maryland	500 (a)	self-unfruitful
"	Lewis and Vincent	Oregon	100 bags	1.0
"	Powell	Delaware	150 (a)	0.0
Stayman	Auchter	Maryland	1500 (a)	self-unfruitful
"	"	"	845 (a)	0.0
"	"	"	560 (b)	0.0
"	Crandall	Illinois	?	0.0
"	Powell	Delaware	106 (a)	0.0
Tompkins King	Auchter	Maryland	1500 (a)	self-fruitful
" "	Chittenden	England	114 (a)	0.0
" "	Gowen	Maine	15	0.0
" "	Lewis and Vincent	Oregon	100 bags	0.0
" "	Morris	Washington	503	0.0
Twenty Ounce	Lewis and Vincent	Oregon	100 bags	0.0
" "	Morris	Washington	519 (a)	0.0
" "	Vincent	Idaho	562 (a)	0.17
" "	Waite	New York	?	self-unfruitful
Wagener	Alderman	West Virginia	3407 (a)	1.26
"	Chittenden	England	210 (a)	0.0
"	Lewis and Vincent	Oregon	50 bags	6.0
"	Morris	Washington	1040 (a)	0.0
"	Vincent	Idaho	7638 (a)	13.2
Wealthy	Auchter	Maryland	1500 (a)	self-fruitful
"	"	"	1059 (a)	4.53
"	"	"	799 (b)	1.88
"	Chittenden	England	30	0.0
"	Lewis and Vincent	Oregon	50 bags	0.0
"	Logsdail	Ontario	172	2.0
"	Morris	Washington	647 (a)	0.46
"	Vincent	Idaho	351 (a)	3.7
"	Waugh	Vermont	28 (a)	0.0
White Pearmain	Auchter	Maryland	500 (a)	self-unfruitful
" "	Morris	Washington	492 (a)	0.61
" "	Vincent	Idaho	540	0.74
Whitney	Auchter	Maryland	1000 (a)	partly self-fruitful
"	Lewis and Vincent	Oregon	100 bags	4.0–
"	Vincent	Idaho	535	0.37

TABLE 19. SHOWING EVIDENCE AS TO SELF-FRUITFULNESS OF IMPORTANT AMERICAN VARIETIES OF APPLES (*continued*)

VARIETY	WORKERS	LOCALITY	BLOSSOMS COVERED (a) OR COVERED AND SELFED (b)	PERCENTAGE OF BLOSSOMS SETTING FRUIT
Williams	Chittenden	England	228 (a)	0.0
"	Powell	Delaware	150 (a)	0.0
"	Waugh	Vermont	63 (a)	0.0
Willow Twig	Crandall	Illinois	?	0.0
" "	Lewis and Vincent	Oregon	50 bags	2.0
Winesap	Auchter	Maryland	1000 (a)	self-unfruitful
"	Crandall	Illinois	?	0.0
"	Lewis and Vincent	Oregon	100 bags	0.0
"	Morris	Washington	1096 (a)	1.6
"	Powell	Delaware	300 (a)	0.0
"	Vincent	Idaho	365 (a)	0.0
"	Wicks	Arkansas	550	0.36
Winter Banana	Morris	Washington	554 (a)	0.0
" "	Vincent	Idaho	763 (a)	0.66
Wolf River	Auchter	Maryland	500 (a)	self-unfruitful
" "	Chittenden	England	84 (a)	11.9
Yellow Transparent	Auchter	Maryland	1000 (a)	self-fruitful
" "	"	"	514 (a)	2.72
" "	"	"	42 (b)	0.0
" "	Crandall	Illinois	? (b)	self-fruitful
" "	Lewis and Vincent	Oregon	25 bags	8.00–
" "	Logsdail	Ontario	605	0.9
" "	Morris	Washington	510 (a)	0.0
" "	Powell	Delaware	363 (a)	5.5
" "	Vincent	Idaho	107 (a)	33.6
York Imperial	Alderman	West Virginia	21742 (b)	0.59
" "	Auchter	Maryland	1500 (a)	partly self-fruitful
" "	Lewis and Vincent	Oregon	100 bags	0.0
" "	Powell	Delaware	134 (a)	0.0

Overholser in some unpublished work in California, with which considerable numbers of blossoms were used, seemed to find Delicious, Gravenstein, Rhode Island Greening, Tompkins King, White Pearmain, and Yellow Bellflower completely or almost completely self-unfruitful.

Of 33 English Apple varieties studied at the John Innes Horticultural Institute by Sutton (327) and Crane (85), the latter lists as self-sterile 2, partially self-sterile 19, and self-fertile or self-fruitful 10.

if they covered more than one cluster with a bag, then the percentages indicated are more than six times too large. Chittenden gives the number of clusters. In the calculations for Table 19, I have multiplied the number of clusters by six to obtain the approximate number of flowers.

The results of the different workers suggest that in a good many climates Baldwin, Green Newtown, Grimes Golden, Ingram, Keswick, Oldenburg, Wealthy, and Yellow Transparent tend to be self-fruitful to a satisfactory degree. This may not mean that the flowers are more highly self-compatible than those of some other varieties. It may mean only that fruit will set with a smaller number of seed or with no seed. Thus, in years when the weather at blooming time is unfavorable for pollination Oldenburg generally sets a good crop; but the average number of seed to the fruit will be smaller than the number in years when the weather at blooming time is favorable. In the Cornell University orchard in 1920 the average number of seeds to the fruit in 449 Oldenburg apples was 6.7; in 1921 the average number was 5.0, 1200 fruits being examined; while in 1922 it was 6.69, 1326 apples being examined. In the springs of 1920 and 1922 the weather at blooming time was more favorable for the setting of fruit than was that of 1921.

The evidence of the table suggests that Ben Davis, Cox Orange, Early Harvest, Esopus, Gano, Gravenstein, Jonathan, Red Astrachan, Red June, Ribston, Rome Beauty, Tompkins King, and Wagener are self-compatible to a lower degree than are the varieties in the first group mentioned; that Fameuse, McIntosh, Northern Spy, Rhode Island Greening, Twenty Ounce, Winesap, Winter Banana and York Imperial are self-compatible only to a very slight extent, and that Arkansas, Arkansas Black, Lawver, Ralls, Shockley, Stark, Stayman, and Williams may be completely, or almost completely, self-unfruitful. With the greater percentage of the varieties studied, however, the evidence is far from being conclusive even for one set of climatic conditions. Usually a rather small number of flowers were covered; and, while in many of the studies records kept of the percentage of the flowers that set fruit when exposed to insect visits showed that percentage considerably higher than the percentage of flowers setting fruit in bags, there is the possibility, previously mentioned, that the conditions in the bag or the effect of the emasculation may have been unfavorable for setting. There are considerable numbers of records of cross-pollinations; and with these the percentages of flowers to set fruit is generally higher than the percentage setting in bags or when covered in other ways; even with varieties that may be classed as self-fruitful. Thus, Lewis and Vincent found that with Green Newtown, a variety that seems to be as dependably self-fruitful as any, a larger percentage of the flowers set fruit from cross than from self-pollination and the fruit was larger and contained more seed. Vincent, Miss Sutton, and Sax give the results of cross-pollinations with a number of the varieties studied as to self-pollination; and the percentage of flowers setting fruit was generally appreciably larger from cross-pollination; but large numbers of blossoms were not used. On the other hand, Powell and Close (67), working in Delaware, and Auchter, working in Maryland, found very few flowers setting fruit from crosses even when considerable numbers of flowers were crossed. Some of the varieties used by these workers have been found to produce pollen a very small percentage of which is viable; but that can hardly be true of all of them.

It may be that cross-incompatibility is rather widespread among apple varieties; but it seems possible that, under climatic conditions prevailing in some of the sections, conditions in the bags or the results of emasculation were so unfavorable for setting that even cross-pollination did not prevent abscission.

Alderman (19) gives very conclusive evidence of the partial self-incompatibility of the varieties that he studied. Using even more blossoms for crossing than the large number given in the preceding table as selfed, he found the following percentages of the flowers setting fruit: Rome Beauty selfed 0.99, crossed 3.41; York Imperial selfed 0.59, crossed 8.29; Wagener selfed 1.26, crossed 8.73.

It seems that in so far as American varieties are concerned, only with such varieties as Arkansas, Arkansas Black, Baldwin, Ben Davis, Esopus, Gano, Gravenstein, Fameuse, Green Newtown, Grimes Golden, Jonathan, Lawver, McIntosh, Oldenburg, Rhode Island Greening, Rome Beauty, Stayman, Wagener, Wealthy, Winesap, Yellow Bellflower, Yellow Transparent and York Imperial is there evidence enough to justify an attempt at very definite rating as to the degree of self-incompatibility. Evidence with the bagging method suggests that the variety Ralls is not self-fruitful. Yet, it blooms so late that in many localities it does not seem probable that there would be other varieties blooming at the same time; and it is notable for the heavy crops of fruit that it sets. Experience in the field is in agreement with the results of pollination studies in the case of some well-known varieties. Thus, in years when the weather at blooming time is very unfavorable for the activities of insects, some of the varieties such as Baldwin and Wealthy that, from the results of pollination studies, seem to be self-fruitful, set very heavy crops; while others such as Rhode Island Greening and McIntosh may set very lightly. Ben Davis when planted in blocks as large as one hundred acres will generally set good crops when the weather at blooming time is warm and sunny; but in less favorable years trees near trees of other varieties will set much the heavier crops. This difference is probably due in part to the greater activity of insects in the favorable years, but it may be due in part also to more effective self-pollination in the favorable years. Of course, it is possible that the difference in behavior between varieties such as Baldwin and varieties such as Ben Davis may be a difference in response to unfavorable weather conditions rather than a difference in degree of self-compatibility.

The evidence we have suggests that with many apple varieties, if not with all, cross-pollination tends to be more effective in causing the setting of fruit than self-pollination. It seems to me, however, that many of the varieties studied may not be as weakly self-compatible as the data indicate. It may be that the emasculation and the bagging or other treatments cause at least a slight reduction in the percentage of both selfed and crossed flowers setting fruit. Generally, if a small percentage of the flowers borne, set fruit there will be a good crop; and so it does not seem certain that with apples a very high degree of self-fruitfulness or very effective cross-pollination is always the most desirable condition. Wealthy sets such heavy crops that very expensive thinning becomes necessary and Wealthy and Baldwin set such heavy crops that fruit buds are not generally formed for the succeeding year; while Rhode Island Greening seldom requires thinning and tends to bear annual crops, the average yield during a considerable period of years being about the same as that of Baldwin. Annual yielding is much the more desirable from the standpoint of the market.

There is not much of convincing data as to cross-incompatibility in the apple. Arkansas, Gravenstein and Stayman seem, under some conditions at least to bear pollen with very low viability. Morris, Powell, Overholser, Auchter and others apparently found cases of cross-incompatibility between varieties bearing viable pollen, but the numbers of flowers used were not generally large. And Morris was not able to find in Washington any orchard, containing two or more commercial varieties, that was not fruiting satisfactorily.

The pear. In the Table 20, on pages 202, 203, is given a summary of the evidence that has come to my attention concerning self-fruitfulness of some of the leading varieties of pears.

Hooper (183), without giving numbers of flowers studied, lists Duchesse d'Angoulême, Beurré Bosc, and Flemish Beauty as being more or less self-fruitful and Doyenné du Comice, Clapp Favorite, Buerré Superfin, and Souvenir du Congrès as self-sterile.

Waite recorded the number of clusters bagged. In arriving at the percentage of blossoms setting fruit he multiplied the number of clusters by 7.5; and for Table 20 the number of blossoms bagged or selfed was obtained for each variety by multiplying Waite's record of the number of clusters by 7.5. In Table 20 the numbers of blossoms crossed and the numbers exposed are not given; however, the number for exposed blossoms was generally larger than the number bagged or selfed. With a few of the varieties the indicated percentage of selfed blossoms setting is too high, since seedless fruits that were small and worthless were counted. With the pear, particularly the Bartlett and the Kieffer, the setting of small seedless fruit is not unusual.

The data in Table 20, suggest that Duchess d'Angoulême, Easter

Beurré, Flemish Beauty, Manning Elizabeth, Glou Morceau and Tyson may fruit well without cross-pollination, at least in some sections in some seasons. Beurré Bosc, Beurré Hardy, Doyenné du Comice, and Seckel seem to be more highly self-compatible than some of the others. Even Bartlett and Kieffer may set good crops from their own pollen in some sections in some years. With nearly all, if not with all, these varieties, a larger percentage of the flowers will set fruit from cross than from self-pollination.

In the work of Waite at Chestnut Farm, Virginia, very few fruits were set from exposed blossoms, though the percentage of blossoms setting fruit from cross-pollination was high. This was an orchard of about 22,000 Bartlett pear trees with only a few trees of Clapp Favorite and a Buffum tree. Only very light crops were ever borne in the orchard. Waite says that Bartlett trees around the Buffum and the Clapp Favorite trees bore much better crops than were borne by other Bartlett trees in the orchard. Tufts and Philp cite equally convincing field observations as to the increased yield of Bartlett orchards due to the presence of trees of other varieties. It is interesting to note that, in the foothills of California, Bartlett flowers, and, apparently, flowers of several of the other varieties, show greater self-incompatibility than in the coastal region or in the interior valley (Davis). The difference with Bartlett is greater than the table indicates. In only one year out of four did any but small seedless fruit set from selfed Bartlett flowers in the Sierra Nevada foothills, though in that year sixteen per cent of the selfed flowers set fruit. In the interior valley some fruit was set from selfed flowers in every year but one out of seven.

There seems to be no evidence of any considerable amount of cross-incompatibility in pears. Duchesse d'Angoulême, Lawrence, Le Conte, Bartlett, Garber, Seckel, and Beurré Clairgeau have been found successfully to pollinate Kieffer; and Doyenné du Comice, Easter Beurré, Howell, Winter Nelis, Duchesse d'Angoulême, Lawrence, Beurré Bosc, Clapp Favorite, Dana Hovey, White Doyenné, Beurré Hardy, Seckel, and Beurré d'Anjou to pollinate Bartlett. In the work of Waite with many varieties cross-compatibility seemed very general. There was no significant evidence that any varieties were incompatible. In the work of Tufts and Philp, Winter Nelis seemed the most effective in pollinating Bartlett and very effective in pollinating other varieties. These workers say that in California the blossoming periods of nearly all pear varieties overlap. Since not all varieties are influenced alike, as to blooming time, by local climatic conditions, it is not feasible to give a list of varieties blooming together except for specific sections.

TABLE 20. SHOWING PUBLISHED EVIDENCE AS TO SELF-FRUITFULNESS OF VARIETIES OF PEARS

VARIETY	AUTHORITY	EVIDENCE				
		LOCALITY	NUMBER OF FLOWERS COVERED OR SELFED	PERCENTAGE OF FLOWERS THAT SET FRUIT		
				selfed	crossed	exposed
Bartlett	Waite (343)	Brockport, N.Y.	180	0.0	......	13.3
"	"	Chestnut Farm, Va.	4860	0.0– 0.12	63.3–100.0	0.0– 0.04
"	"	Rochester, N.Y.	3488	0.3– 4.4	0.0– 77.7	7.9–35.3
"	"	Geneva, N.Y.	668	0.0	......	11.7–13.9
"	Fletcher (133)	E. Lansing, Mich.	3081	0.19	8.1– 21.0	......
"	Tufts & Philp (335)	Davis, Calif.	3369	0.0– 9.7	2.1– 26.6	0.1– 8.2
"	" "	Coast region, Calif.	1527	0.5–12.4	0.4– 24.2	1.2–20.0
"	" "	Foothills of Calif.	2876	0.0–16.0	1.8– 27.2	2.7–19.5
Beurré Bosc	Waite	Rochester, N.Y.	315	0.6	......	20.6
" "	"	Geneva, N.Y.	270	0.0– 2.4	......	0.0– 3.0
" "	Tufts and Philp	Davis, Calif.	227	0.0	......	26.1
" "	" "	Coast region, Calif.	410	20.0	......	26.0
" "	" "	Foothills of Calif.	1048	0.0– 2.1	4.6– 9.3	4.0– 4.5
Beurré Clairgeau	Waite	Rochester, N.Y.	712	0.0	......	9.0–22.5
"	"	Geneva, N.Y.	188	0.0	......	16.0
"	"	" "	248	0.0	0.0– 25.0	15.0–19.3
"	Tufts and Philp	Davis, Calif.	1306	0.0– 7.3	10.6– 14.5	5.5–23.8
"	" "	Coastal region, Calif.	422	0.0	1.4	4.8
Beurré d'Anjou	Waite	Brockport, N.Y.	488	0.0– 0.7	......	15.7
"	"	Chestnut Farm, Va.	173	0.0	......	24.1
"	"	Rochester, N.Y.	2078	0.1– 1.2	8.0– 31.4	13.3–18.6
"	"	Geneva, N.Y.	1230	0.0	0.0– 25.0	0.0– 9.9
"	"	" "	285	0.0	50.0	10.0–12.1
"	Tufts and Philp	Davis, Calif.	1124	0.6–20.4	......	7.0–17.3
"	" "	Foothills of Calif.	787	0.0	5.7– 14.6	2.8– 4.1
Beurré Hardy	" "	Davis, Calif.	1199	0.3– 9.3	4.7– 14.7	3.5–13.6
" "	" "	Coastal region, Calif.	404	1.2	27.0– 35.7	3.4
Beurré Superfin	Waite	Rochester, N.Y.	1185	0.0	......	15.4–19.0
Clapp Favorite	"	Brockport, N.Y.	278	0.0	......	19.2
"	"	Chestnut Farm, Va.	248	0.0	......	6.6
"	"	Rochester, N.Y.	968	0.0	31.0	14.2–17.7
"	Tufts and Philp	Davis, Calif.	630	0.6– 2.6	......	8.7–14.0
Columbia	Waite	Rochester, N.Y.	1927	0.0	......	7.9–12.6
Dana Hovey	Tufts and Philp	Davis, Calif.	1141	0.0–11.7	......	2.4–19.5
" "	" "	Foothills of Calif.	148	0.0	2.5	12.4
Doyenné du Comice	" "	Davis, Calif.	1665	1.2– 6.5	......	2.3–19.9
" "	" "	Coastal region, Calif.	425	0.9	0.6– 29.9	4.0
" "	" "	Foothills of Calif.	1880	0.0– 0.5	0.0– 11.9	0.0– 3.7
Duchesse d'Angoulême	Waite	Brockport, N.Y.	2003	3.8–18.5	......	1.0–36.3
"	"	Rochester, N.Y.	1223	2.8– 7.8	22.5	3.8–14.9
"	"	Geneva, N.Y.	412	2.4–11.7	......	1.2–17.2
"	Tufts and Philp	Davis, Calif.	776	0.0– 6.4	......	0.1–10.0
Easter Beurré	Waite	Rochester, N.Y.	967	0.2	......	7.0
" "	Tufts and Philp	Davis, Calif.	948	0.7– 6.3	......	3.7– 4.0
" "	" "	Coastal region, Calif.	486	11.3	......	4.4
" "	" "	Foothills of Calif.	274	3.0	6.6	5.2

TABLE 20. SHOWING PUBLISHED EVIDENCE AS TO SELF-FRUITFULNESS OF VARIETIES OF PEARS (*continued*)

VARIETY	AUTHORITY	EVIDENCE				
		LOCALITY	NUMBER OF FLOWERS COVERED OR SELFED	PERCENTAGE OF FLOWERS THAT SET FRUIT		
				selfed	crossed	exposed
Flemish Beauty	Waite	Rochester, N.Y.	615	10.7	......	20.7
"	Tufts and Philp	Davis, Calif.	226	6.2	......	18.2
Forelle	" "	Davis, Calif.	787	0.0	......	8.7–25.2
Glou Morceau	" "	Davis, Calif.	583	0.6– 2.1	......	3.4– 3.9
" "	" "	Coastal region, Calif.	892	8.4	12.0– 15.0	6.1
Howell	Waite	Rochester, N.Y.	750	0.1	......	16.2
"	Tufts and Philp	Davis, Calif.	1147	0.3– 4.4	......	0.6– 6.8
"	" "	Coastal region, Calif.	531	0.0	......	1.2
Kieffer	Waite	Rochester, N.Y.	488	0.0	100.0	17.7
"	"	Geneva, N.Y.	271	0.0– 1.4	33.3	14.9–18.5
"	Fletcher	Martinsburg, W.Va.	780	0.5	13.8– 35.8	......
"	"	E. Lansing, Mich.	488	0.2	7.0– 20.2	......
"	Powell (272)	Newark, Del.	596	0.0	16.6	......
"	"	" "	687	0.014	7.3	......
"	Tufts and Philp	Davis, Calif.	1261	0.0– 5.5	......	4.9–14.9
Le Conte	Waite	Rochester, N.Y.	908	0.05–5.6	0.0– 40.9	13.3
"	Tufts and Philp	Davis, Calif.	1095	0.0	......	3.6–14.0
Lawrence	Waite	Rochester, N.Y.	1305	0.0	......	11.9–14.5
"	"	Geneva, N.Y.	495	0.0	0.0– 25.0	3.7– 8.1
(Manning) Elizabeth	Waite	Geneva, N.Y.	368	19.0–42.5	......	20.0–44.1
Mt. Vernon	Waite	Rochester, N.Y.	713	0.1	......	14.8
Seckel	Waite	Brockport, N.Y.	1582	1.0– 3.3	......	1.0– 3.0
"	"	Rochester, N.Y.	1335	0.0– 7.0	......	20.3–39.0
"	"	Geneva, N.Y.	1238	0.0– 1.1	12.5	0.0– 8.2
"	Tufts and Philp	Davis, Calif.	1504	0.0–19.8	......	15.0–77.5
Sheldon	Waite	Rochester, N.Y.	840	0.0– 0.3	......	6.9–11.7
"	"	Geneva, N.Y.	225	0.0	......	2.9
Souvenir du Congrés	Waite	Rochester, N.Y.	570	0.7– 2.1	......	20.7–22.3
Tyson	Waite	Rochester, N.Y.	203	12.8	......	30.0
Winter Nelis	Waite	Brockport, N.Y.	120	0.0	......	35.3
" "	"	Rochester, N.Y.	2903	0.0– 0.7	43.3– 55.7	7.5–13.3
" "	Tufts and Philp	Davis, Calif.	2144	0.0– 0.2	16.5	6.0–12.4
" "	" "	Coastal region, Calif.	971	0.2– 1.4	8.0– 17.0	4.5–10.0
" "	" "	Foothills of Calif.	938	0.0– 0.5	3.1– 27.3	1.2–10.0

In the northeastern part of the United States some pear varieties tend to drop the fruit badly even when there is adequate provision for cross-pollination. This is particularly true of Beurré d'Anjou, which also shows that characteristic in Pacific coast sections. Rather severe cutting back of the twigs or branches in the spring before the flowers open has sometimes caused much better crops to set. As to how generally such a practice would be effective toward insuring the setting of fruit with trees having adequate provision for cross-pollination, we have not sufficient data or experience for a conclusion.

The quince. Waite (344) seemed to find, though he does not give his data, that Orange Rea, Champion, and Meech quinces are self-fertile and apparently do not require insect visitation. However, quince varieties, at least in Northeastern United States, tend to bear rather light crops, a large percentage of the flowers falling.

The plum. Waugh (346–49) seemed to find self-incompatible all plums of American species that he tested except Robinson. Some of them had a large percentage of defective pistils but not enough to account for their self-sterility. It does not seem necessary to give his results here since these American plums have not yet proved to be of much importance. Dorsey (107) also found a number of American varieties self-sterile. He found a rather high percentage of the pollen aborted; but with very few varieties did he find the percentage of aborted pollen large enough to explain the self-sterility of the variety. Waugh tested by bagging also a few varieties of the Japanese plums (*Prunus salicina*), and found them apparently self-sterile. Thus, no fruit was set when 57 blossoms of Chabot, 71 of Engre, 92 of Kerr, 409 of Maru, and 190 of Ogon were covered with bags. Hendrickson (175–177) studied the following varieties of this species: Abundance, Apex, Beauty, Burbank, Climax, Combination, Formosa, Duarte, El Dorado, Formosa, Gaviota, Kelsey, Methley, Prize, Santa Rosa, Satsuma, Sultan, Upright, and Wickson, and found only Beauty, Climax, Methley and Santa Rosa self-fruitful. He used so many blossoms that there seems to be little question as to the dependableness of his results, though he was working with varieties with which the normal percentage of flowers to set was low. With Burbank, 2957 selfed blossoms failed to set a fruit; while the percentage of flowers to set when pollinated with Satsuma, Climax, Wickson, and Sultan was 17.5, 15.1, 15.0, and 18.0. Abundance set 0.1 per cent when selfed and 15.4 per cent when crossed. At Ithaca, New York, during the season of 1919 he (176) found the Burbank self-sterile but pollinated by Reine Claude. This is of interest since Marshall (234) seemed to find that *Prunus salicina* does not cross with *Prunus domestica*. MacDaniels (223) enclosed a tree of Burbank and one of Reine Claude under a mosquito bar tent with a hive of bees. Some fruit set on the Burbank tree, but not nearly as much as set on Burbank trees exposed to the visits of insects carrying other pollen, some of which was probably from Abundance trees. Of course, there is the possibility that at Ithaca during the blooming season of these very early blooming varieties bees were less active than some other insects that may have been visiting flowers not under the mosquito bar covering. Hendrickson (177) found later that Tragedy, another variety of *Prunus domestica,* is a very effective pollinizer of nearly all the Japanese varieties with which he tried it, though no Japanese variety would successfully pollinate Tragedy. Hendrickson thinks that this may possibly be explained by the facts that pollen of Japanese sorts tends to germinate slowly and the pistils of Tragedy are very long. The ovules may, therefore, begin to disintegrate before this weakly growing pollen reaches them. While Reine Claude pollen seems to cause a light fruiting and Tragedy pollen abundant fruiting of some Japanese varieties, it is the very general experience that the European plums are incompatible with both Japanese and American plums. In fact, *Prunus domestica* does not seem readily to cross with other species; and there are among known varieties very few hybrids of this with other species. On the other hand there are many hybrids between Japanese varieties and varieties of American species; and it is probable that more varieties of these last are compatible with Japanese varieties. All Japanese varieties that Hendrickson studied were cross-fruitful except Formosa and Gaviota. These two were cross-fruitful with other Japanese varieties, but highly cross-incompatible with each other. He considers Beauty, Burbank, Santa Rosa, Duarte, and Wickson among the most effective pollinaters of Japanese varieties.

In New York, the Burbank plum seems to set very much heavier crops in orchards containing other Japanese varieties than it sets in plantings containing only Burbank and European varieties. In fact, when grown near other Japanese varieties it often sets such extremely heavy crops that thinning becomes very expensive and that in spite of thinning the fruit is reduced in size. It is possible that if Burbank were pollinated only by some slightly compatible variety like Reine Claude, or if there were only a few trees of another Japanese variety widely scattered in the Burbank orchard, this variety might be more profitable even though the total crop were slightly smaller.

Not as large a percentage of varieties of the European species, *Prunus domestica* and *Prunus insititia* are self-sterile as of Japanese varieties and those of American species; and so it seems well to use a table showing the experimental results with some of the leading European varieties.

Of 31 English varieties of Insititia and Domestica plums studied at the John Innes Horticultural Institute Crane lists as self-sterile 16, partly self-fertile 5, and self-fertile 10.

The numbers of blossoms crossed and the numbers counted in deter-

TABLE 21. SHOWING RESULTS OF STUDIES AS TO SELF-COMPATIBILITY OF SOME VARIETIES OF PLUMS

VARIETY	WORKERS	LOCALITY	NUMBER OF BLOSSOMS SELFED OR COVERED	PERCENTAGE OF FLOWERS SETTING FRUIT		
				selfed	crossed	exposed
Agen (Prune d'agen)	Crane (85)	England	325	0.0	15.6 –24.0	...
“	Hendrickson (175)	Davis, Calif.	2743	3.02	6.6 –10.6	33.0
“	“	Cupertino, Calif.	2948	9.6	21.10–23.5	4.2
“	“	Saratoga, Calif.	5052	5.05	10.9 –22.8	7.0
“	Marshall (234)	Riddle, Oregon	623	4.9	3.5 –14.1	...
“	“	Corvallis, “	166	0.6	3.4 –10.2	...
“	Sutton (327)	England	many	0.0	3.4 – 5.7	...
Clyman	Hendrickson	Davis, Calif.	1126	0.0	1.2–18.1	25.9
“	Marshall	Corvallis, Ore.	311	0.0	2.6	...
Diamond	Hendrickson (177)	Vacaville, Calif.	310	15.8	4.9–16.5	...
“	“	Newcastle, Calif.	922	0.1	0.0–40.4	0.6–1.6
German Prune	Hendrickson (176)	Ithaca, New York	426	0.0	29.6–47.4	20.0
Giant	Hendrickson	Newcastle, Calif.	139	10.8	5.2–34.8	22.0
“	“	Vacaville, Calif.	291	3.1	0.9– 8.7	29.1
“	Marshall	Coravallis, Ore.	262	0.4	7.9	...
Golden Drop	Backhouse	England	many	0.0	......	...
“ “	Marshall	Riddle, Ore.	600	0.0	7.8–13.2	...
“ “	“	Corvallis, Ore.	1443	0.0	4.6– 8.9	...
“ “	Rawes (281)	England	221	0.0	......	5.0
“ “	Sutton	“	many	0.0	0.0–25.1	...
Grand Duke	Hendrickson	Davis, Calif.	684	0.01	0.0– 6.9	31.5
“ “	“	Vacaville, Calif.	470	1.5	1.1–26.0	7.3
“ “	“	Newcastle, Calif.	742	0.54	1.1–30.7	5.5
“ “	Rawes	England	313	0.0	......	...
Imperial Epineuse	Hendrickson	Cupertino, Calif.	1083	0.3	1.3– 6.0	3.5
“	“	Saratoga, Calif.	4010	1.5	5.0– 8.7	7.25
“	“	Vacaville, Calif.	231	0.0	......	4.8
Italian Prune	Marshall	Corvallis, Ore.	2633	3.1	0.0–14.0	...
“ “	“	Riddle, Ore.	684	8.3	0.0– 3.0	...
Jefferson	Crane	England	146	0.0	0.9–76.2	...
“	Rawes	“	187	0.0	......	...
“	Sutton	“	114	0.0	0.0–27.4	...
McLaughlin	Crane	England	231	0.0	25.8–73.6	...
“	Sutton	“	656	0.15	14.3–48.3	...
Pond	Crane	England	336	0.0	16.9–61.6	...
“	Hendrickson	Newcastle, Calif.	50	4.0	11.0–14.4	11.9
“	“	Davis, Calif.	306	4.2	7.5–21.3	41.7
“	“	Vacaville, Calif.	259	0.0	0.5– 1.6	...
“	Marshall	Corvallis, Ore.	212	0.0	0.0– 4.0	...
“	“	Riddle, Ore.	300	0.0	8.6–18.8	...
“	Rawes	England	162	0.0	......	...
“	Sutton	“	moderate number	very few	?–73.2	...
President	Crane	England	54	0.0	0.0–61.1	...
“	Hendrickson	Newcastle, Calif.	709	0.0	0.0–37.3	2.7
“	“	Vacaville, Calif.	355	0.0	0.0– 7.1	3.2
“	Rawes	England	489	0.6	25.5	...
Reine Claude	Hendrickson (176)	Ithaca, New York	312	12.8	0.6–13.8	7.1
“ “	Marshall	Corvallis, Ore.	320	1.9	0.0– 3.6	...
“ “	Sutton	England	many	?–23.0	......	...
Sergeant	Hendrickson	Davis, Calif.	2754	0.16	10.5–45.1	19.7

TABLE 21. SHOWING RESULTS OF STUDIES AS TO SELF-COMPATIBILITY OF SOME VARIETIES OF PLUMS (*continued*)

VARIETY	WORKERS	LOCALITY	NUMBER OF BLOSSOMS SELFED OR COVERED	PERCENTAGE OF FLOWERS SETTING FRUIT		
				selfed	crossed	exposed
Shropshire	Hendrickson	Ithaca, New York	599	2.0	12.0–13.6	5.8
Standard	Hendrickson	Vacaville, Calif.	330	0.0	3.9–15.6	8.1
Sugar	Hendrickson	Davis, Calif.	417	8.1	0.8– 2.7	41.6
"	"	Cupertino, Calif.	1074	8.4	11.1–13.9	11.7
"	Marshall	Corvallis, Ore.	218	2.3	0.5– 9.0	...
Tragedy	Hendrickson	Davis, Calif.	3679	0.02	0.7–27.7	20.9
"	"	Vacaville, Calif.	359	0.3	0.0– 2.3	0.9
"	"	Newcastle, Calif.	418	0.0	0.0–53.0	0.26
"	Marshall	Corvallis, Ore.	288	0.0	1.7– 6.9	0.0
Victoria	Backhouse (33)	England	140	nearly 100.0	......	...
"	Sutton	"	many	many	......	...
"	Crane	"	115	51.3	24.1–70.5	...
Washington	Hendrickson	Vacaville, Calif.	411	0.0	......	...
"	Rawes	England	105	0.0	......	...
Yellow Egg	Backhouse (33)	England	300	nearly 100.0	......	...
" "	Hendrickson	Vacaville, Calif.	219	11.4	......	...
" "	Sutton	England	many	many	......	...

mining the percentages of exposed blossoms setting are not given in Table 21, but they were generally proportional to the numbers selfed. With plums, nearly all of the workers hand selfed the flowers; and so these selfed flowers had precisely the same treatment as the crossed ones except for the different pollen used. A comparison of the column for selfed results with that for crossed results strongly suggests that all but a few varieties are partly or completely self-incompatible. Agen, Giant, Italian Prune, Reine Claude, Sugar, Victoria, and Yellow Egg seem dependably self-fruitful, though crossed flowers of Agen seem to set better than selfed ones. Grand Duke, and Imperial Epineuse appear slightly self-compatible. Possibly some of the varieties that failed to set any fruit from selfed flowers might have set some if more flowers had been used.

We have seen that Hendrickson (174) found that with Agen insect application of its own pollen increases the percentage of flowers setting. Thus, when a single tree of Agen was covered with a tent that apparently excluded all insects the percentage of flowers setting fruit was very small while when a single tree of Agen was enclosed in a tent with a hive of bees the percentage of flowers setting was higher than the average for the variety in the orchard. And keeping bees in an Agen orchard increased the percentage of flowers to set. As to how general with self-fruitful varieties of plums this need for insect application of pollen may be we cannot be very certain since so few self-fruitful varieties have been studied by merely excluding insects without hand selfing. Of interest in Hendrickson's work is the fact that the Agen tree, which was caused by the presence of a hive of bees to set a very heavy crop in 1916, set a very light crop in 1917. This suggests that with heavy blooming varieties partial self-incompatibility works toward annual bearing of medium crops, a condition very desirable commercially.

Nearly all varieties of Domestica plums studied are cross-compatible. While varieties of *Prunus domestica* and *Prunus insititia* are generally rather highly incompatible with Japanese varieties and varieties of American species, there is little evidence of cross-incompatibility between *Prunus domestica* and *Prunus insititia.* In the work of some of the authors quoted in Table 21 some crosses between varieties of these two species failed to set any fruit, but not enough flowers were used to furnish conclusive evidence. Since Japanese varieties seldom if ever effectively pollinate Domestica varieties, and only a few Domestica varieties have been found effectively to pollinate Japanese varieties, one should not plant an orchard composed of only one Domestica variety and one Japanese variety unless the varieties concerned had been proved to be self-compatible.

The cherry. Gardner (139) made a very extensive study of the pollination problems with the sweet cherry (*Prunus avium*) with the surprising result that each of a rather large number of varieties was almost completely or completely self-sterile, though germination tests showed that each bore viable pollen. His evidence seems unusually conclusive. He selfed or bagged from one thousand to more than five thousand blossoms of the following varieties: Bing, Black Tartarian, Coe, Early Purple, Elton, Knight, Lambert, Lincoln, Major Francis, Napoleon, Republican, Rockport, Willamette, Windsor, and Wood. With no variety did as many as one per cent of the blossoms used set fruit and even the few fruits set were all in muslin bags which he thinks may have permitted cross pollination in these few cases. The evidence is stronger because of the fact that normally from twenty to forty per cent of sweet cherry blossoms set fruit, and in Gardner's work as many as 55 per cent of the cross-pollinated flowers set fruit. Tufts (331) seemed to find Bing, Black Tartarian, Lambert, Napoleon and Republican self-sterile in California. Tufts and Philp in some work in California, not yet published, found self-sterile most of the varieties studied by these other workers and in addition Abundance, Advance, Black Heart, Burbank, Burr, Chapman, Centennial, Cleveland, Downer, Mezel, and Pontiac. Miss Sutton (327) found Black Eagle, Black Heart, Black Tartarian, Elton, Napoleon, Wood, and other varieties of sweet cherries studied, self-sterile in England, though Hooper (183) without giving his data reports having found Napoleon self-fruitful. He found Black Eagle, Elton, and Knight self-sterile. Crane (85) found self-sterile the twenty-three English varieties of sweet cherries that he studied and Florin (135) found the same for all sweet cherry varieties of Sweden that he studied.

The well-known varieties of sour cherries (*Prunus cerasus*) seem nearly all to be self-fertile. In the season of 1914, Mr. E. D. Vosbury bagged flowers of most of the varieties of sour cherries grown at the New York State Experiment Station and found all setting well in bags. Miss Sutton (327), Hooper (183), and Backhouse (32) found English Morello self-fruitful. Crane (85) found English Morello, Wye Morello, and a form of Kentish Red self-fertile and another form of Kentish Red self-sterile.

Of the Dukes, which Hedrick *et al.* (164) consider to be hybrids between *Prunus avium* and *Prunus cerasus*, only a few have been studied as to self-compatibility. In Gardner's work in Oregon two thousand blossoms of May Duke set only six fruits and these were in the muslin bags. Miss Sutton in England obtained only twenty-three fruits from 3182 selfed blossoms, though Late Duke set well and Arch Duke in fair percentage from selfed blossoms. Backhouse (32) reports Late Duke as self-fruitful in England. Crane (85) lists Late Duke as self-fertile and May Duke and Royal Duke as partly self-fertile.

Gardner seemed to find a greater degree of cross-incompatibility among sweet cherry varieties than seems to prevail among varieties of other fruit species studied. Thus, Bing, Lambert, and Napoleon, the three leading varieties of the Pacific Northwest seem to be incompatible, and he records a considerable number of other varieties that seem to be cross-incompatible. Except with Bing, Lambert, and Napoleon, his experimental evidence concerning cross-incompatibility is not as strong as that concerning self-incompatibility. The number of flowers used was rather small, being from 25 to 277, more often than otherwise being less than 200. There are inconsistencies that suggest that the experimental error was rather large. Thus Republican pollinated with Lambert failed to set at The Dalles and set 16 per cent at Corvalis, while Lambert pollinated with Knight failed to set at Corvalis and set twenty per cent at The Dalles. These inconsistencies suggest that failure to set is far from being conclusive proof that there would have been no fruit set if much larger numbers of blossoms had been crossed. However, the total number of crosses among Bing, Lambert, and Napoleon was 3612 and only five fruits were set. He gives also the results of observations in orchards at The Dalles during the summer of 1912. Unless other varieties were near enough for cross-pollination, Napoleon, Bing, and Lambert were bearing light crops when large blocks contained only one or more of these three varieties. Trees of Bing, Lambert, or Napoleon were fruiting heavily when trees of Republican were near. When seedling trees were near most varieties were fruiting well. Crane (85), using rather small numbers, seemed to find a considerable amount of cross-incompatibility among sweet cherry varieties. It would seem that in planting any sweet cherry variety one should always be certain to have adjacent trees of some variety known to be compatible. Gardner found Republican, Black Tartarian, Waterhouse, Elton, Coe, Wood, Oxheart (of America), Early Purple, and apparently Rockport and Windsor good pollenizers for Bing, Lambert, and Napoleon.

Gardner says a few orchards of Napoleon (Royal Ann) fruit well in Oregon apparently without the possibility of pollen from another variety; and he suggests that several similar varieties or strains may be grown in Oregon under the name of Royal Ann. Tufts and Philp think this may be true in California of Napoleon and of some other old varieties, different strains of Napoleon, for example behaving differently as to cross-compatibility with other varieties. It is not impossible, that seedling strains may be grown that cannot easily be distinguished from the parent variety.

Of interest is the question as to whether or not varieties of the sour cherries and of the Dukes are compatible with the varieties of the sweet cherries. Gardner seemed to find May Duke incompatible with Willamette and Knight, only slightly compatible with Napoleon and Bing, and fairly compatible with Lambert. Miss Sutton found May Duke pollinated reasonably successfully by some sweet cherry varieties and pollinating some sweet cherry varieties fairly successfully; and Arch Duke and Late Duke fairly compatible with some sweet cherry varieties. Hooper (183) and Miss Sutton found English Morello and Kentish Red compatible with a number of sweet cherry varieties. Crane (85) seemed to find sour cherries and Dukes more effective in pollinating sweet cherries than were the sweet cherries in pollinating sour cherries and Dukes. Thus, of 1121 sweet cherry blossoms pollinated by sour cherries and Dukes 28.9 per cent set fruit; while of 866 flowers of sour cherry and Duke varieties pollinated by sweet cherries 8.7 per cent set fruit. However, it may be that if more flowers and more sour cherry and Duke varieties had been used the results would have been different.

The peach, the nectarine, and the apricot. Close (67) found the following peach varieties setting well in bags: Old Mixon, Reeves, Elberta, Globe, Crawford Late, and Fox; and Fletcher (133) found the Gold Drop self-fruitful. In crossing work at the University of Missouri generally blossoms that were bagged before opening set fruit readily. It seems to be true that important American peach varieties are generally self-fruitful and that self-pollination is the general rule even in orchards containing many varieties. Thus, of many crosses made between varieties with purple coloring in the twigs and varieties without such coloring all progeny has had purple twigs. Yet of hundreds of unguarded seedlings, from Snow and Ortiz trees surrounded by purple twig varieties, none have had purple twigs. In other words it seems that all of the flowers of Snow and Ortiz had been self-fertilized. Conners (78) reports J. H. Hale self-sterile and bearing no viable pollen.

In some unpublished work in California Overholser found Early Newington, Humbolt, and Lord Napier nectarines self-compatible. Austin (30c) found Blenheim, Hemeskirke, Lewis, Montgamet, Moorpark, Routier Peach, Royal, and Tilton apricots highly self-compatible. He found suggestive, but not conclusive, evidence that insect application of the pollen is necessary if the largest possible percentage of the flowers are to set. However, since far too many apricots are likely to set and thus to be too small, in spite of expensive thinning, improved pollination agencies are not necessarily desirable.

The almond. Tufts (332) self-pollinated during the season of 1916 from 450 to 1586 blossoms of each of the varieties: California, Drake, Harriott, I.X.L., Jordan, King, Languedoc, Lewelling, Ne Plus Ultra, Nonpareil, Peerless, Princess, Reams, and Texas; and during the season of 1917, 237 to 1189 blossoms of each of the same varieties and also of Big White Flat, Golden State, and Klondike. In 1919 Tufts and Philp (334) pollinated nearly as large numbers of flowers of these varieties and also of Eureka, Sellers and Silver Shell. Not one per cent of the blossoms of any variety set fruit except in the case of Harriott, Big White Flat, Sellers, and Reams. With Harriott, 15 per cent of the selfed blossoms matured fruit in 1916, but only 0.08 per cent in 1917 and 1.3 per cent in 1919. With Big White Flat 2.5 per cent of the selfed blossoms matured fruit in 1917 and 0.2 per cent in 1919; with Sellers 1.4 per cent of the flowers set fruit in 1919 and with Reams 1.2 per cent. All of the varieties studied were found to produce viable pollen. With them, therefore, self-sterility is due to self-incompatibility. While, with a few varieties, fair crops may set from self-pollination in some years, for satisfactory yields all require cross pollination.

With most varieties, in cross-pollinations studied by Tufts and Tufts and Philp rather high percentages of flowers set fruit that matured. However, Nonpareil and I.X.L. seemed incompatible and also Texas and Languedoc. They seemed to find that, even in orchards of mixed varieties, in California, if bees were not kept, the yield was reduced.

The grape. We have seen that the work of Beach (41), Booth (51), Dorsey (105), Detjen (102), and others indicated that the varieties of grapes that have been found self-sterile are so not because of self-incompatibility but because of abortive pollen. With some varieties bearing abortive pollen the stamens are recurved with small anthers; with others they are erect and crinkled; while with others they are normally upright. According to Beach (39) the varieties America, Aminia, Barry, Black Eagle, Gaertner, Herbert, and Massasoit are completely self-sterile and Brighton, Eumalon, Lindley, Vergennes, and Woodruff so near to being completely self-sterile that the clusters are not marketable unless the flowers are cross-pollinated. Unlike most kinds of tree fruits much the larger number of grape varieties are self-fruitful. Booth found that the pollen of Aminia, Barry, Black Eagle, Massasoit and some other self-sterile varieties would not germinate in sugar solution. Beach (40) had found that pollen of self-sterile varieties was as ineffective when used in crossing as when used in selfing. Plants of *Vitis rotundifolia* generally produce only abortive pollen or only staminate flowers; but a few varieties bearing self-fertile hermaphrodite flowers have been originated.

Stout (322) has studied seedlessness in Lubrusca grapes and finds that the flowers of varieties bearing seedless grapes have long stamens with well-developed anthers and pollen with an unusually high germination ability. While the pistils seem to be normal, he thinks seedlessness is due to weak femaleness.

Some small fruits. Of small fruits Hooper (184) reports gooseberries and currants as self-fruitful, but requiring insect application of the pollen. He reports also that English varieties of raspberries are self-fruitful.

Detjen (101) has made a careful study as to self-fruitfulness of blackberries and dewberries. He found in North Carolina that all varieties of blackberries tested were self-fruitful, except Rathbun which was partly self-sterile and McDonald, Sorsby, and Spalding, which would set no fruit in bags. These four are all hybrids. The entirely self-fruitful varieties included Blowers, Early Cluster, Early Harvest, Eldorado, Illinois, Mersereau, Minnewaske, Snyder, and Wilson (this last a hybrid). Of dewberries Austin, Lucretia (*Rubus flagellaris*), Cox and Ruth (hybrids) were self-fruitful; while Premo (*Rubus flagellaris*) and all of the varieties of *Rubus trivialis* were self-sterile. He used generally less than a hundred bags but the percentages of flowers setting were either very large or practically nothing, and so his evidence seems reliable. Germination tests showed that the pollen of self-sterile varieties is viable. From experience with plantings of one variety there seems to be little doubt but that the common varieties of raspberries are self-fruitful.

I know of no experiences with varieties of strawberries that are self or cross-incompatible. Self-sterility with that fruit when it exists seems always to be due to failure to produce viable pollen. Varieties that fail to produce viable pollen are generally called pistillate varieties. According to Hooper (184) wind pollination is the rule with this fruit. Self-sterile plants should, therefore, be only a few feet from pollen-bearing plants. The strawberry flower contains many pistils. Some of these may fail to be pollinated or the pistils may be sterile. According to Valleau (340) fertility of the pistils decreases in the later flowers of an inflorescence. If a considerable percentage of the pistils are sterile an irregularly shaped berry may be produced, such as may be produced as a result of injury to the berry from insect punctures. The latest flowers in an inflorescence may be entirely sterile. Gardner (142) seemed to find a relation between the number of non-abortive pistils to the flower and the size of the berries. Even when he removed the first eight flowers of a cluster as many fruits were borne as with clusters having no flowers removed; but the number of pistils to the berry was smaller and the berries averaged smaller.

The filbert. Schuster (303), working in Oregon during the seasons of 1920 and 1921, self-pollinated flowers of a rather large number of varieties of filberts and found only about one per cent setting fruit, though 37 to 57 per cent of exposed blossoms set. He seemed to find that some varieties are also cross-incompatible. However, Barcelona was pollinated reasonably well by all well-known varieties grown in Oregon, and DuChilly, an important commercial variety, proved a good pollinater, so, also, did Cosford, a variety less well known. The pollen is carried by the wind; Schuster found that it cannot be carried more than about one hundred feet; and trees sixty feet from another variety seem in some years to have the crop thereby reduced. Since the pollen is wind carried, rainy weather during the winter months when pollination takes place may be harmful. However, the blooming season is long, a pistil is receptive during a rather long period; and the pollen is very durable, a fair percentage remaining viable as long as thirty days. Further, during wet weather the anthers remain closed. Thus, the washing away of the pollen is inhibited.

Some subtropical fruits. *The date.* It is well known that the date is diœcious; and it is the common practice to tie a part of a cluster of opening staminate flowers to a cluster of pistillate flowers. This operation generally has to be repeated since not all of the pistillate flower clusters are receptive at the same time. Usually about one staminate tree is necessary for one hundred pistillate trees. Wind pollination may be fairly successful if many more staminate trees well distributed in the planting are used.

Citrus fruits. I do not know of any reports of self-incompatibility among citrus fruits. A number of varieties set seedless fruit. With the Washington Navel orange the pollen is abortive and cross-pollination is generally ineffective in causing the formation of seeds, normal ovules capable of being fertilized seldom being formed. The fruit is, thus, truly parthenocarpic. We have seen that Coit and Hodgson (71, 72) found that the young fruits of this variety drop very badly in orchards located where transpiration is very great during early summer. Some of the seed-bearing varieties hold their fruit better under such climatic conditions.

Reed (285) studied the flowering and fruiting of the Lisbon lemon. He found that 66 per cent of the blossoms appeared in March and April, 13 per cent in November, 17 per cent between April and November, and 3 per cent during the winter months. The clusters opening in the spring contained the largest average number of flowers. A flower in a cluster containing few flowers had a better chance of developing into a mature fruit than one in a many-flowered cluster. Of the blossoms studied 51.98 per cent set fruit, 21.71 per cent reached a diameter of one-fourth inch and 6.62 per cent reached maturity. A fruit set in the spring months had the greatest chance of reaching maturity.

The avocado. In the United States there is a considerable amount of loss from failure of avocado flowers to set fruit. A part of this may be due to unfavorable climatic conditions. The avocado is native to a humid climate; and, in some parts of California, it is being grown where the humidity is rather low. The fruit has been in cultivation in such sections during too short a time for many varieties resistant to such conditions to have been developed. However, even in the more humid sections where conditions seem favorable, its flowers often fail to set fruit. Nirody (252a) may have found the explanation in the nature of the opening of the flowers. He finds that on one day a flower opens and the pistils are receptive but no pollen is shed, while in the succeeding day the same flower opens again and sheds pollen. All the first opening of flowers of a variety being at about the same time in the day. Stout (323) found that in California the pistils have become darkened at the end and nonreceptive when the flower opens the second time and the pollen is shed. He found also that with a single variety the first opening of the flowers when the pistils are receptive is at a different time of the day from the second opening. Thus, unless pollination can occur while the flower is closed, self-pollination is nearly impossible. Nirody found with Fuertes, however, that the flowers opening the first time may remain open until other flowers are opening the second time and pollen is being shed. Stout seemed to find that not all varieties can pollinate all other varieties. Some have the first opening with receptive pistils at the same time of day, while the desirable condition would be for the first opening of one to be coincident with the second opening of the other so that there would be available pollen and receptive pistils at the same time. Thus, with Dickinson, Sharpless, and Taft at 11 A.M. the only flowers open will be those opening the first time and having receptive pistils, but no available pollen, while at 3.30 P.M. the only flowers open will be those opening the second time having available pollen but pistils past the receptive stage. On the other hand, with Fuertes in the morning, flowers opening the second time will be shedding pollen when the pistils of Dickinson flowers are receptive; and in the afternoon Dickinson flowers will be shedding pollen while Fuertes pistils are receptive. Stout divides the varieties into two classes, those with which the first opening, with the receptive pistils, is in the morning and the second opening, with the available pollen, is in the afternoon, and those with which the first opening, with the receptive pistils, is in the afternoon and the second, with the available pollen, is in the morning. Naturally varieties of the first could be pollinated only by varieties of the second class; and the reverse. Of course, we know nothing as yet concerning the possible extent of cross-incompatibility among varieties whose blooming habits favor cross-pollination. Stout seemed to find that bees are not very active in visiting avocado flowers. For these reasons it may be that avocado trees should be planted closer to a pollinating variety than is necessary with other fruits. However, it should be considered that only a small percentage of the flowers setting fruit would be enough for a good crop. It may be that the possibilities for self-pollination are not so remote as these papers indicate. Only after much more study and experience can we be certain to what extent lack of cross-pollination and to what extent the physiological condition in the tree determines the dropping of avocado fruits.

The persimmon. The American persimmon (*Diospyrus virginiana*) is generally diœcious though some wild trees bear both staminate and pistillate flowers. Trees or branches bearing staminate flowers are, of course, necessary for the setting of fruit on trees or branches bearing only pistillate flowers. With the Japanese persimmon (*Diospyrus Kaki*), some varieties bear both staminate and pistillate flowers; while others bear only pistillate. According to Hume (192) some varieties bear both staminate and pistillate flowers one year and only pistillate the next, or bear staminate flowers irregularly; and some, while in the main bearing imperfect staminate and pistillate flowers, bear occasionally perfect flowers. Yasui (364) says that *Dyospyrus Kaki* is normally monœcious, but that staminate flowers are disappearing under cultivation. The perfect flowers are found toward the terminal of the fruiting shoot and have usually the smaller pistils. In Florida some varieties, according to Hume, will set fruit without pollination. Others will not set unless pollinated; and still others will bear well in some years without pollination, but in other years will not set fruit unless pollinated. Condit (76) thinks that in California such varieties may set more dependably without pollination, and that the presence in the planting of pollen-bearing trees may cause the setting of too heavy crops.

Hume (192) reports a very interesting influence of seed formation on some varieties, such as Zengi and Hyakume, which will set seedless fruit without pollination, but with pollination will set fruits with seeds. The seedless fruits have a light-colored flesh, while with these varieties seed formation causes the flesh to be of a dark color. If only one seed forms it is surrounded by dark flesh, the remainder being of a light color. Three or four seeds well distributed may be enough to give all of the flesh a dark color, though a fruit with four seeds all on one side would probably have light-colored flesh on the other side. With nearly a full quota of seeds the flesh is all of a dark cinnamon color. With the varieties Okame and Yemon, even with a full quota of seeds dark flesh is only in areas around the seed; and these areas are all included in a mass of light-colored flesh. Some varieties such as Tsuru and Hachiya are light fleshed whether seedless or not. No dark-colored seedless variety is known in the United States. The fruits of the varieties Zengi and Hyakume tend to be smaller when seed is formed, and Zengi tends to have a form different from that of seedless fruit of the same variety. It is possible that these differences may be partly explained by the heavier crop.

The fig. Condit (77) places the varieties of figs in four classes: the common figs (comprising nearly all of the many varieties grown in Europe and America) which will set fruit without pollination but may be pollinated; the Smyrna figs (comprising such varieties as Calimyrna and Rixford) which will not set fruit without pollination; the San Pedro figs (comprising such varieties as White Pedro and the Gentile) which will set a first crop each year without pollination, while the second crop requires pollination or the young fruit will fall; and the caprifigs among which there are a few varieties that bear edible fruit, but which are important mainly for the pollination of varieties of the other types. Since the pollen for Smyrna figs or others that are pollinated is furnished by caprifigs, pollinization is generally referred to as caprification. Concerning this process, there is an extensive literature which is reviewed at length by Eisen (120). The flowers of the fig are borne on the inner lining of the hollow fruit. Except with the caprifigs only pistillate flowers are borne. With the caprifigs there are many stamens near the small opening at the apex of the fruit. Farther back from the apex are pistils many of which are modified, being much shorter than the normal ones. These are known as gall flowers. If the caprifigs are useful in pollinating other varieties they are inhabited by a small wasp (*Blastophaga grossorum*) which deposits its eggs in these gall flowers. In fact, the fruits will generally fall before maturity unless inhabited by these insects. The caprifigs borne by a single tree during a year are generally divided into three classes; profichi, or figs that start from wood one year old or sometimes older, about the time the leaves start in the spring; mammoni, or figs that start in early summer in the axils of the leaves of current season wood; and mamme, which are the same as the mammoni except that they start later in the summer. It is in these and some of the mammoni that the *Blastophaga* live through the winter. It is from the profichi that the pollen is carried to the young Smyrna fig. The adult female *Blastophaga* in going out of the caprifig becomes covered with pollen which she carries to the young fig which she enters for the purpose of depositing eggs. If she enters a Smyrna fig there are no gall flowers and she perishes, but in seeking such flowers into which to deposit eggs she applies the pollen to the normal pistils. Pollination is not satisfactory if caprifig trees are merely planted in the orchards. It is best to gather the caprifigs and hang them in the Smyrna fig trees. In California various kinds of baskets are used as containers. Caprification can begin when the Smyrna figs are about three eighths to one half of an inch in diameter. According to Condit it is best to hang caprifigs in the tree every three or four days during a period of about three weeks. Naturally the larger the tree the more caprifigs are used. While a second crop of San Pedro figs may be obtained by caprification, these varieties seem to be grown generally for the first crop which does not require caprification. Varieties of common figs may be pollinated from caprifigs and the nature of the fruit will be somewhat different from that set without pollination. Condit says that the quality of dried Adriatic Mission and Dottato (Kadota) figs is somewhat improved by caprification. When Dottato figs are used for preserving the uncaprified fruit is the better.

Summary. Besides the influence of physiological conditions, a variety may fail to set fruit because its own pollen is abortive and it does not have pollen from another variety, because it is self-incompatible and does not have pollen from another variety, or, it seems, with a few varieties at least, because its own or other pollen is not applied by insects.

With the apple a few varieties produce little or no viable pollen. Many varieties of apples and pears are self-incompatible to such a degree that, at least under most climatic conditions, they will set very small crops in some or most seasons if they do not have pollen from another variety. While we cannot say from the available evidence that any variety of apples or pears will set as well from self-pollination as from cross-pollination, a few varieties will set from self-pollination crops large enough; or even too large. There is little evidence of cross-incompatibility among varieties of apples or of pears that bear fair amounts of viable pollen.

Nearly all varieties of American and Japanese plums seem to be self-incompatible and a few are cross-incompatible. Japanese and American varieties are generally cross-incompatible with European varieties; but pollen of a few European varieties will cause the setting of fruit of Japanese plums; though most of the fruit set does not bear viable seed. Some of the varieties of European plums are self-fruitful to a very high degree, though a larger number of varieties seem to be at least partly self-incompatible.

All varieties of sweet cherries studied are self-incompatible to a high degree and there is evidence of much cross-incompatibility. Sour cherry varieties seem generally self-fruitful, and some varieties of the Dukes are self-fruitful though others seem self-incompatible, at least to a considerable degree. Neither of these last two classes has been studied as thoroughly as the sweet cherry has.

Self-unfruitfulness in varieties of grapes seems to be due to lack of viable pollen rather than to self-incompatibility. This seems to be true also of strawberries. A few varieties of blackberries, all hybrids, have been found self-incompatible and all dewberries belonging to the species *Rubus trivialis;* also one variety belonging to *Rubus flagellaris.*

CHAPTER 12

FRUIT THINNING AND ALTERNATE BEARING

We have seen that, when the bloom is heavy, not only is there a very large percentage of the flowers that fall without setting fruit, but many of the fruits that set fall during what is known as the "June drop." Heinicke (166) found that with a normal bloom the smaller the number of flowers falling without setting fruit, the larger will be the "June drop." Generally with a normal bloom the percentage of flowers that develop into mature fruit is rather small. Thus, Gardner (139) found with some varieties of sweet cherries that 28 per cent of the flowers setting fruit would give a full crop, while Hendrickson (175) found with some varieties of plums that if 3.5 per cent of the blossoms set fruit a good crop may be obtained. Reed (285) found that in commercial orchards only 6.62 per cent of the blossoms of Lisbon lemons develop into mature fruit. Tufts (333) found with the Bartlett pear at Davis, California, that, in 1916, 3.6 per cent of the blossoms set fruit and the crop was 3510 pounds to the acre, while, in 1917, 8.2 per cent of the blossoms setting fruit gave a yield of 3840 pounds to the acre, the bloom being the heavier in 1916. In other words, if it were not for the abscission of the blossoms and the young fruit, the crop set would, with most kinds, be far too large for fruit of desirable size and quality to be produced. Even after the "June drop," the crop is often much too large; and with some kinds thinning the fruit is a necessary orchard practice. This thinning may be merely the removal of all but one of the fruits in each cluster, or it may be such a spacing that the fruits will be six, eight, or even ten inches apart along the branch. Such thinning may be desirable for its effect on the fruit or for its effect on the tree.

Effect on the fruit. From the work of Beach (42), Auchter (26, 28), and others, and from a lot of observation in practice, it is certain that, with apples when the crop is very heavy, thinning will improve the color of the fruit. Such a result is to be expected, since, when the fruits are very close together, and especially when the branches are bent down upon each other, so that there are masses of fruit and leaves, some of the fruits will be completely shaded; and with few of them will the surface be exposed to direct sunlight as it would if they were far enough apart on the branches not to touch each other. It is probable that the benefit to color produced by thinning is greater than would be produced merely by the increased amount of light reaching parts of the surface. We have seen that the fruit on trees well irrigated late in the growing season has a brighter color than that on trees with an inadequate water supply. With fruit on trees having only an adequate crop, there seems to be a greater brightness due to healthy development as well as to the increased amount of red over the surface. While there is not the experimental evidence, it seems certain that, with trees bearing a very heavy crop, thinning improves the color of peach fruits as much as it improves that of apple fruits, or more.

Close (66), Beach (42), Fisher (131), Herrick (178), Ballou (35), Batchelor (38), Auchter (26, 28), have studied the effect of thinning on the size and the market quality of apples. In a few cases the total yield of fruit on thinned trees was larger than that on unthinned ones. It seems probable, however, that this may have been due to variation among the experimental trees. The unthinned ones may have been a little the larger. In nearly all cases the average total yield on the unthinned trees was a little the higher. However, in many cases when the trees were bearing heavy crops, the yield of marketable fruit was the greater on the thinned trees. And, of course, in all cases the amount of fruit in the higher grades was increased, particularly when the fruit was left six to ten inches apart on the branch. Beach calls attention to the fact that the profit in thinning will be greatly influenced by market opportunities. If a grower sells his fruit nearly all in one grade, then he will receive very little more because of the presence of a fair number of fancy apples on his trees. Such a grower should leave his apples about four to six inches apart on the branch. However, if a grower is sorting his fruit into a number of grades, he will receive a rather largely increased price for the larger size and better color. Wider spacing on the branch would then be profitable. It is very difficult to determine the net cost of thinning apples. Of course, the cost will vary with the size of the trees and the amount of thinning required. Beach estimated the cost of thinning the very large apple trees of New York to be about fifty cents a tree, with the labor prices of 1902–03. It took about a half-hour to five hours to thin a tree. A part of the cost of thinning, though seldom all of it, is offset by the reduced cost of harvesting and grading. Under average market conditions, thinning when the crop is heavy is unquestionably profitable from the standpoint of the fruit alone. When the crop is rather light but in parts of the tree the fruits are a little closer to each other than they would be left in thinning a tree that has set a heavy crop, the experience of Auchter indicates that thinning may reduce the yield without measurably improving the quality of the fruit. Some varieties like Wealthy, Winesap, Wagener, and Baldwin that tend to set very heavy crops will often require rather expensive thinning, while, in the northeastern part of the United States, at least, varieties like Rhode Island Greening and McIntosh that tend to drop their fruit badly will not often require much thinning.

Varieties of pears, except Kieffer, in climates where there is much cold weather at blooming time, at least, seldom set large enough crops to make thinning necessary. Kieffer, under good conditions for pollination, often sets excessively heavy crops. With mature trees, however, the heavy pruning, which with this variety is desirable for other reasons, may take the place of thinning.

Apricots in the climate of the Pacific Coast set very heavy crops which must be thinned unless the pruning is very severe. Pruning severe enough to render thinning unnecessary rather greatly reduces the yield. On the other hand, in California, at least, no amount of thinning will cause the fruit to be as large on lightly pruned trees as it would become following heavy pruning.

A few very brief experimental studies of the effect of thinning peaches have been made, but none that seem to add anything to what is known from the experience of growers. The trees of many varieties tend to set and hold such large crops that, without thinning, the fruit may be very small, sometimes almost worthless. With such varieties no experiment is necessary to learn the value of thinning. While Elberta, the leading market variety, fruits more dependably than most other varieties and often sets crops heavy enough to make thinning desirable, as the results of Close (66) emphasize, I know of no experience in which healthy trees failed to bear fruit large enough to be marketable. This may be because Elberta is naturally a large peach; but with this variety, when the crop is excessively heavy, enough fruits generally fall during the summer to leave space for the remainder to develop at least small marketable size.

With some varieties of plums, some thinning is often desirable, not only in order to obtain fruit of good size, but, in some climates, also because brown rot spreads more rapidly among fruits that touch. The amount of thinning that will be profitable will be largely determined by market opportunities. The price of even high-grade plums is often so low that laborious thinning may be unprofitable. Of course, on account of the large number of fruits, the labor of hand-thinning plums is very great. With the Burbank variety, growers in New York sometimes knock some of the fruit off by striking them with a knotted rope. This does not thin the fruit evenly, but it gets a lot of it off and permits most of the remainder to develop fair size. It is not improbable that with Burbank it would be well to have in the orchard only a few widely scattered trees of another Japanese variety so that only a small percentage of the flowers would be pollinated. The average crop would probably be smaller, but the cost of thinning might be avoided and the fruit would probably be larger; for when the fruit of this variety sets very heavy, pulling off the excess fruits at the earliest possible time apparently will not prevent that left from being smaller than it would have been if less fruit had been set.

The effect on the tree. Auchter (26) has emphasized the fact that excessively heavy crops may be very injurious to trees, especially young trees, both by breaking and injuriously bending the branches and by causing a weaker growth generally. Pickering (872) has shown that fruiting may greatly reduce the growth of trees. Gourley (150) found that the leaves tend to be smaller, and apparently that there is less starch stored in the wood in the year when the tree is bearing a heavy crop. The results of Kraybill (212) suggest that there tends to be more nitrogen and possibly less starch in the tissue in summers when the tree or branch is bearing a crop than in summers when it is not. Hooker and Bradford (182) seemed to find, during mid-summer, reducing sugar in greater quantities and starch in smaller quantities in the bark and spurs of fruiting than of non-fruiting branches, and that the diameter increase of a branch is less in its fruiting than in its non-fruiting year. That the leaves are smaller and the total leaf surface considerably smaller in the year when the tree is bearing a heavy crop was indicated in results at Cornell University (782), where the total leaf surface was determined each year for a rather large number of trees. And measurements of hundreds of trees showed forcibly that the annual increase in trunk diameter tends to be strikingly reduced in the year when the tree is bearing a heavy crop. Not only is the percentage of girth increase greater in a year when the tree does not bloom, but this is true also in a year when the bloom is killed by a frost. And when trunk growth is so greatly reduced, root growth also must be reduced, it seems, as greatly.

Thinning must cause considerable reduction in the amount of material used in the fruit; for it generally causes a reduction in the total crop. The amount of dry matter in the fruit must be more largely reduced than is the total weight; the larger fruit on the thinned trees seems to be the more succulent. Then the cores and seeds would be about as large in the unthinned as in the thinned fruits. In other words, probably a larger percentage of the thinned crop than of the unthinned is water. It seems at least probable that, as soon as large numbers of fruits are thinned off, materials that would have been used by these fruits are available for growth of root and top. Since the thinning is done so late that the terminal buds have generally formed, it cannot influence top growth in the same year unless it be the thickening of the trunk and large branches. It seems possible, however, that it may influence root growth very appreciably. And, if the root hairs are mainly on very young roots, such an increase in the rate of root growth might considerably influence the water supply to the tree during the same summer. It does not seem impossible that an important item of the cause of the increased size of the fruit on thinned trees is a greater root growth due to the release of organic or other materials that would have been used by the fruit if some had not been pulled off. However, without thorough study, we cannot be certain that root growth is so increased by thinning. It may be that much of the material that is used in the formation of fruit would otherwise go into the formation and deposition in the cell walls of increased amounts of gums and cellulose that may be of little value toward increasing the growth and bearing capacity of the tree.

It should be emphasized that not all the reduction in tree growth in the year of a heavy crop is due to the material used by the fruit after it has become large enough for thinning to be done; that is, after the "June drop." The great reduction in leaf surface must all, or nearly all, be caused before that time. In fact, with apple and pear trees, the leaves of a heavily blooming tree are noticeably smaller before the bloom has fallen. The mere formation of many blooms greatly inhibits spring growth. This fact is strikingly illustrated by some experiments at Cornell University. It was thought that removing the bloom as it opened, and thus preventing the diversion of material to fruit growth, would cause a more rapid growth of young trees. The early fruiting Oldenburg variety was used, the trees being in pairs and one of each pair having all the bloom removed each year when the buds were opening. Many more fruit buds were set on the non-fruiting trees. When the orchard was six years old, the ones permitted to fruit having set a fair crop in the previous year, the average number of flower clusters on ten fruiting trees was 190, while the average on ten trees having the blossoms removed was 556. When it was seven years old, the average on the fruiting trees was 444, and on those with the blossoms removed it was 1274 flower clusters. After two years of fairly heavy fruiting and one in which a small number of fruits were borne to the tree, if the ones with the blooms removed were larger than the fruiting ones the difference could be detected only by digging up and weighing the trees. Apparently the dwarfing effect of the excessive bloom on the one had been about as great as the dwarfing effect of the fruiting on the other. It should not be assumed, however, that thinning would increase the amount of bloom in the succeeding year and thus offset the effect on the tree of the reduced number of fruits. Removing some of the fruits at thinning time does not seem to influence the number of flowers borne in the succeeding year. With young trees the greatest injury from a heavy crop is often due to the excessive bending and breaking of the branches, and certainly the fruit should be removed that would cause such injury.

Alternate bearing. The habit of bearing only in alternate years is common to many varieties of apples and pears and to at least one plum, the Sugar prune. It seems to be true with nearly all tree fruits that during the year when a very heavy crop is being borne there is a tendency to set a small number of fruit buds. However, with most of the stone fruits and with many varieties of apples and pears some fruit buds are set while the tree is bearing a heavy crop. Generally a much smaller number of flowers than that normally borne is enough for the setting of a heavy crop. And, if weather conditions at blooming time are reasonably favorable, there may be no apparent alternating as measured by yield of mature fruit; even when a heavy crop markedly reduces the number of fruit buds set. Pickering (269) did not find in the English climate pronounced tendency toward alternate bearing for the varieties he used. The fluctuations in fruiting observed he thought could be explained by influences such as spring frosts or cold weather at blooming time. Of course, in determining the effect of a crop on fruit-bud formation the bloom in the succeeding spring and not the resulting crop should be considered, since so many factors at blooming time influence the crop. And since the branches of a tree may not alternate together — that is, they may fruit in different years — not tree yield but branch yield should be considered in studying alternate bearing.

Certainly any one who works with apple trees in America knows that many varieties tend to alternate. Thus, Beach, Booth, and Taylor (43) describe as biennial fruiters, or nearly so, eighteen of thirty-five leading New York varieties. With many varieties this tendency to alternate a heavy crop with a light crop or no crop begins with the first rather heavy crop. In New York, for more than twenty years preceding 1923, such a large proportion of the Baldwin trees had their non-bearing year in the odd year that the price of apples for the country was almost uniformly better on the odd than on the even year. Growers spoke of the even year as the "Baldwin year." If the bearing year for a tree were determined entirely by individual orchard conditions, there should be about as many trees bearing in the even years as in the odd years, and there should be many trees with some branches bearing in the even years, and some in the odd years. There must have been some general influence that affected the bearing habit of all of the trees. If weather conditions in one year should be unfavorable for fruit-bud formation, all the trees, having a rest in the succeeding year, would probably set a heavy crop of buds; or, if weather conditions in spring or insect or fungous injury should cause nearly all the blossoms or very young fruit to fall, a heavy setting of fruit buds on all the trees might follow.

Butler (56) explains alternate bearing by the nature of the growth of apple and pear trees. Thus he says:

> Owing to the fact that, with few exceptions, spurs only flower on alternate years, it must follow that after an apple tree begins to form new growth slowly and bear heavily, a light crop must necessarily follow a heavy crop, for, when the flowering of the spurs synchronizes to such an extent as to give a large yield, the same spurs are not in a position to bear again until the next succeeding year. Alternate bearing in mature apple trees is, therefore, a natural phenomenon and one that could be predicted from the mode of flowering of the tree.

It would seem that this theory must presuppose that young growing trees do not alternate; for, considering the case of a six-year-old tree bearing in 1916, the fruit was on spurs from axillary buds of 1913 or 1914; if the tree had been growing regularly and each year increasing greatly the number of twigs, it is evident that there should have been many more axillary buds in 1914 or 1915 to give fruit in 1917 than there were in 1913 or 1914 to give fruit in 1916. Yet, in the Cornell Experiment Station orchard such vigorous young trees of a number of varieties bore rather heavy crops in 1916, and had almost no bloom in 1917, although the summer of 1916 was so favorable for fruit-bud formation that healthy trees but three years old set many fruit buds. It is very common for some varieties such as Ralls to begin alternating when fruiting begins, even though annual length growth is good every year and a sufficient number of new spurs are therefore formed each year for a fair crop. While this matter will be given more consideration later, it may be said here that it seems certain that with alternating varieties not nearly all of the spurs fruit or even bloom in the fruiting year for the tree. Alternate bearing, then, cannot be explained solely by the morphology of the tree, but must result at least partly from some physiological influence that is general in the branch. In fact it would require a physiological stimulus to cause the spurs to begin to bloom all in the same year. It seems probable that this influence may be associated with that which so greatly reduces the growth of the tree in the year when it is bearing a heavy crop.

Effect of thinning on alternate bearing. The assertion is often found in horticultural literature that thinning the fruit will tend to prevent alternate bearing. However, the results of Beach (42) did not indicate that thinning one crop caused a larger crop to be borne the next year. Gourley (150) reports a similar experience. Auchter (26, 28) studied this problem very extensively, in most cases with trees bearing heavy crops. On account of crop loss by spring frosts in one year, his data, so far as the effect on alternating is concerned, are for but three years. The results indicate no measurable influence of thinning on alternate bearing. More conclusive information would be obtained if the thinning could continue from the time the trees begin to fruit to the age when the alternate bearing habit is strongly fixed in unthinned trees. For it seems possible, though not probable, that thinning might prevent the beginning of alternating, even though it might not represent an influence strong enough to break the habit when once fixed. There is evidence, however, that even when the first heavy crop is thinned, the number of fruit buds set is still very small. Thus, in the Cornell Experiment Station orchard, Jonathan, Red Canada, Wealthy, Wagener, a few Baldwin trees, and McIntosh bore crops in their sixth summer (1916). In order to prevent the bending of the branches injuriously, this crop was thinned more than would be done in best commercial practice. Yet Jonathan, Red Canada, and Baldwin trees had nearly no bloom in 1917, McIntosh a light bloom, and Wealthy and Wagener had practically only bloom from axillary and terminal twig buds, though the weather of 1916 was favorable for fruit-bud formation, the bloom of 1917 being heavy on trees that had not borne in 1916.

Other influences. A considerable amount of attention has been given to the behavior of spurs of alternate and annual bearing trees. Wiggans (361) studied the behavior of apple spurs in Missouri, finding with Gano, Rome, and Jonathan that respectively 8.2, 8.5, and 15.8 per cent of the spurs that fruited in 1913 bloomed in 1914, though considerably larger percentages of the spurs that bloomed in 1913, but did not set fruit, bloomed also in 1914. Auchter (28) found in West Virginia that, while many of the spurs may bloom in successive years, it is very seldom that a spur fruits one year and blooms the next. Thus, 162 spurs of the 525 labeled ones on a Grimes Golden tree bloomed in each of the years 1917 and 1918, but only four of these had fruited in 1917. Fifty-four Rome Beauty spurs bloomed in both 1917 and 1918, but only eight of these had fruited in 1917. Fifty-three Rome Beauty spurs bloomed in both 1918 and 1919, but only five of these had fruited in 1918. Of 224 spurs (of a Delicious tree) that fruited in 1917, only twelve bloomed in 1918, though 101 spurs bloomed in both the years 1917 and 1918. Of 113 spurs (of a Delicious tree) that fruited in 1918, only ten bloomed in 1919, though 200 spurs bloomed in both the years 1918 and 1919 on this same Delicious tree. Thus, even with trees that tend to bear annual crops, the individual spurs tend to alternate. Setting a fruit tends strongly to inhibit fruit-bud formation by a spur, but blooming, if it has such a tendency, has it only slightly, provided no fruit is set.

Roberts (292) seemed to find a relation between the spur length and annual bearing. He classifies spurs as follows: short spurs averaging 2.55 millimetres in the season's length growth and bearing terminal leaf buds; non-fruiting spurs averaging 4.28 millimetres in length of the season's growth bearing terminal blossom buds, but setting no fruit; spurs which set fruits and average 12.14 millimetres in length of the season's growth; long spurs which average 18.14 millimetres in the length of the season's growth and bear terminal leaf buds. He says, of course, that these classes blend into each other and some fruit is borne by spurs of all the lengths. He found that in the bearing year the spurs tend to come in the short non-fruiting class, while in the off year the spurs tend nearly all to be of the lengths most favorable for fruit-bud formation. He says that to obtain annual fruiting the tree should be so treated as to cause many of the spurs to be long ones, only a moderate percentage of which will bloom, the excessive bloom thus being avoided and annual fruiting promoted. However, Auchter and Schrader (30b) found in Maryland that, while, with trees or branches in annual bearing, the fruiting of the spurs is in approximate agreement with the results of Roberts, with trees or branches in alternate bearing, disregarding the very weak continuously non-fruiting ones, spurs of all lengths tend to set fruit buds in the non-bearing years and spurs of no length form buds in the bearing year. It does not follow that because, with trees bearing a medium crop, spurs of a certain length do not form fruit buds the same would be true with trees bearing no crop. It may be that the tendency for spurs of medium length to form fruit buds in larger percentage than with longer or shorter spurs is present also in the non-bearing tree, but that without the inhibition to fruit-bud formation caused by the crop of fruit all the spurs tend to set fruit buds. In fact, with non-bearing trees under good condition for fruit-bud formation, not only do spurs of all lengths form fruit buds, but shoots of all lengths up to three or four feet may form both terminal and lateral fruit buds.

And not heaviness of bloom alone, but percentage of flowers setting influences the tendency toward alternate bearing. There are generally many non-fruiting spurs of all lengths even in the bearing year of an alternate bearing tree; but, with some varieties, if a rather large crop is borne, it inhibits fruit-bud formation in the non-fruiting spurs even though there may be large numbers of these. Baldwin is one of the most striking varieties in its alternating habit, and yet it seems to be generally a rather light bloomer. Often in New York the bloom will be very light, though rather well distributed. The crop will be reported small; but later it will be found that, on account of the large percentage of the flowers setting, the crop is a good one. Sometimes the bloom and the crop will be mainly on the terminal of twigs; much the larger number of the spurs being without bloom, yet there will be little or no bloom in the succeeding year.

What evidence we have seems to support the conclusion that a heavy bloom on a branch tends to inhibit fruit-bud formation, but not as much as does the setting of a heavy crop of fruit; and that the inhibition is greater in the spur bearing the bloom or fruit than in adjacent spurs, but that there is some inhibition, often enough to prevent fruit-bud formation, in adjacent non-fruiting spurs or in shoots on the same branch. Fruiting in a branch of fair size may possibly exert some inhibiting influence on fruit-bud formation on an adjacent branch; but that influence cannot be very strong; for one secondary branch may have its off year and set many fruit buds, while another on the same branch is bearing a heavy crop.

With Wealthy and Wagener apple trees in the Cornell Experiment Station orchard a heavy crop reduces the tendency to form terminal and axillary fruit buds on the new shoots. Roberts, however, says that it is not the blooming or the bearing of the crop that causes the off year; but rather it is the physiological condition of the tree — of which condition the heavy bloom is an expression. This view seems not to be generally applicable; for, if the heavy bloom is killed off by frost, or if, due to imperfect pollination, it falls without setting much fruit, there will generally be fruit buds formed.

As to how a heavy bloom followed by a heavy crop of fruit inhibits fruit-bud formation, possible explanations, it seems, might be: using nearly all of the supply of one or more of the mineral nutrients (however, Kraybill (212) seemed to find a slight increase in nitrogen during the bearing year); reducing the supply of carbohydrates generally, or of some particular carbohydrate or carbohydrate-nitrogen compound (Kraybill (212) seemed to find a slight increase in free reducing substances and perhaps a slight decrease in starch and acid hydrolyzable materials in the year of a heavy crop); depletion, through fruit formation or seed formation, of some substance that may be present in small quantities, but that is necessary for the initiation of fruit-bud formation; a developing in the tissue of a general chemical condition that is unfavorable for fruit-bud formation; an unfavorable carbohydrate-nitrogen relationship.

Methods of reducing alternating. Roberts suggests that the use of readily available nitrogen in the orchard very early in the spring may reduce the tendency of the trees toward alternate bearing, the principle being that the nitrogen so increases the growth of the spurs that some will be too highly vegetative to set fruit buds and may therefore set fruit buds in the succeeding year. He makes it clear, however, that abundant use of nitrogen cannot be expected always to prevent alternate bearing; trees that have been too weak vegetatively to set many fruit buds might be increased in vigor just enough to set an excessively large number of fruit buds and, in the succeeding year, to set such a heavy crop of fruit as to prevent fruit-bud formation. And some varieties, in the climate of New York at least, bear alternate crops in spite of the greatest vigor of growth that it seems possible, through soil management alone, to induce the trees to make.

Crow and Eidt (89) seemed to cause annual fruiting in mature Wealthy apple trees by applying sodium nitrate in early spring of the off year, and giving a well-distributed cutting-back of the branches also in the off year. At the Cornell Experiment Station, cultivated trees of Wealthy and other apple varieties have not been caused to bear annually by such cutting-back and fertilizing in every spring with sodium nitrate. In the work of Crow and Eidt it may be that the annual bearing resulted as much from withholding the nitrogen in the bearing year as from applying it in the off year. We have seen that if the nitrogen supply at blooming time is low, many of the flowers may fail to set fruit. If a light crop were caused in such a way, fruit buds might be formed while the crop was being borne. However, in a well-cultivated orchard the nitrogen supply would generally be large enough for the setting of a good crop of fruit even if nitrate were withheld in the bearing year. And, in the climate of New York at least when the seasons are favorable for fruit-bud formation, the application of any amount of nitrogen in the off year will not generally cause such a vigorous vegetative growth but that fruit buds enough for an excessive crop may be formed.

Hooker (632) found that, when the nitrogen is applied in the fall or late summer, there is apparently more starch and more nitrogen in the tissue in June, the time of fruit-bud differentiation, of the following year. He thinks that fruit-bud differentiation while the tree is bearing a crop might thus be stimulated.

Roberts recommends pruning, well distributed throughout the top of the tree, especially in the off year, as another means of increasing vigor of spur growth and reducing the percentage of the spurs that set fruit buds in any one year. Pruning certainly tends to have such an influence. However, much pruning tends to reduce the bearing surface and, therefore, the possible crop of fruit; and the amount of pruning necessary to prevent alternate bearing will vary with the variety and with weather conditions at blooming time and during the period of fruit-bud formation. Whether or not the amount of pruning necessary to prevent alternate bearing will be so great as appreciably to reduce the average crop is a problem for each variety and for each set of climatic conditions under which each variety is grown. It is probable that with the soil water and mineral nutrient supply continuously abundant and with no summer days favoring high transpiration, a medium amount of annual heading-back and thinning-out of the top of apple trees might with nearly all varieties cause the setting of moderate numbers of fruit buds every year; provided exceptionally favorable weather at blooming time in some year did not cause such an unusually high percentage of the flowers to set fruit as to prevent fruit-bud formation in spite of any degree of vigor attainable except by means of excessive pruning. However, such weather conditions, exceptionally favorable for fruit-bud formation, are to be found in some year in nearly all fruit sections. It seems to me that, under some conditions, doing much well-distributed pruning — thus removing wood containing fruit buds — in the dormant season before the fruiting summer, might, by preventing an excessive bloom and the setting of an excessive crop of fruit, and also by invigorating the weak non-fruiting spurs, cause the formation of fruit buds while the crop is being borne. The best way to cause the setting of fruit buds annually seems to be to prevent the setting of excessive crops; and the most effective preventive of the setting of excessive numbers of fruit buds is a medium to light crop on the trees. It should be emphasized that many varieties tend but slightly to alternate bearing; and the one known dependable means of insuring annual setting of fruit buds is to select varieties that do not have, or that have but slightly, the tendency toward alternate bearing.

With alternating varieties it seems possible by removal of blossoms to cause some of the trees or some of the branches of each tree to bear in the off year for the others and thus to obtain annual bearing in the orchard; though I know of no recorded experiences where such a condition has been brought about artificially except with the Japanese persimmon described by Ikeda (837), who says that near a city in Japan there are two small sections where Japanese persimmons are grown for marketing in the city. In order that the market may not be glutted, the growers of one section remove the blossoms in one year from any tree that tends to bear when the crop will be obtained in the other section. This results in fruiting the following year, non-fruiting the next, and so on. Thus, while the trees regularly alternate in both sections the crop of one is borne in a different year from that of the other.

Summary. When the crop of fruit set on the trees is very heavy, thinning it so that the fruits are left four to ten inches apart on the branches will increase the size of all kinds and will improve the color of apples, peaches, and other kinds that require direct sunlight for the development of red color. When the crop set is not so heavy that without thinning a considerable amount of the fruit will be unmarketable, the profit from thinning may depend upon the availability of a market for the higher grades of fruit at prices well above that for fruit of medium grade. A heavy crop reduces the growth of the tree, and thinning may be beneficial to the tree, not only by preventing the breaking or injurious bending of the branches, but by diverting to the use of the tree, for growth of roots or other parts, material that would have been used for the excessive fruits. The evidence does not indicate that thinning tends measurably to influence the tree toward regular annual bearing. A heavy crop inhibits fruit-bud formation in the entire branch or tree bearing the crop, both on the spurs bearing fruit and on the spurs and twigs without fruit, though the inhibiting influence is greatest on the spurs bearing the fruit. While good soil management and pruning may reduce this inhibiting effect of a crop by reducing the tendency toward excessive blooming, for varieties with a strong tendency toward alternate bearing there is no conclusive evidence that, except under unusually favorable soil and climatic conditions, annual crops can be obtained from all the branches without unprofitable reduction of the average annual crop by excessive pruning. The only known dependable means of obtaining annual crops is to select varieties with a strong tendency toward annual bearing.

CHAPTER 13

ORCHARD SOIL MANAGEMENT

Tillage in the orchard may involve a fall or spring ploughing succeeded by varying numbers of cultivations with a light implement such as the disc harrow or a spring-tooth harrow; or all of the work may be done with the harrow, the ploughing being used only in years when, for any reason, the soil becomes too hard to be worked with a disc harrow. Some cultivate only a few times in a year, sowing a cover-crop or letting the weeds begin to grow for a cover-crop as early as June. On the other hand, some growers may work the soil as often as fifteen or twenty times during a season, sowing the cover-crop, if one is sown, generally late in August or in September.

Until the last forty or fifty years most of the orchards in America were in sod. Perhaps during the last twenty-five years tillage has been increasingly the predominant practice. However, many orchards are still grown in sod or in what Gourley (613) has called a grass mulch; that is, a mulch formed by the accumulation of the grass that is cut once or twice a year and left where it falls. While the orchard is young, the grass may be piled around the trees. This may form a very effective mulch until the spread of the roots becomes so great that the grass which can be grown in the orchard is not sufficient for an effective mulch. In some orchards extra material such as manure or straw is brought in for use as a mulch.

Effect on the trees of tillage and of sod. The practice of cultivation has generally been assumed to benefit the trees through its effect on soil moisture; and we have seen that Emerson (598) and Woodbury, Oskamp, and Noyes (736) found tillage to have a rather large influence on the moisture percentage in the soil, and that these workers, Stewart (709), and others found growth in young trees greatly influenced by the amount of water retained in the soil. On the other hand, we have seen that, when the roots are widely and thickly distributed in the soil, the water loss from the surface, whether there is a dust mulch or not, is insignificant compared with the amount lost through transpiration from the trees and from the plants between the trees.

The influence of tillage on the soil water supply is probably due much more largely to its preventing the growth of plants that would transpire water than to its maintenance of a dust mulch that reduces the amount of water lost from the surface. It would be expected, therefore, that tillage would influence the soil water supply much more in young orchards than in orchards in which the trees were large enough to cover nearly all the soil. For with the large trees the amount of water transpired from grass and weeds would probably be insignificant compared with the amount transpired from the trees; and in most of the experimental orchards in which the soil moisture supply was much greater with cultivation the trees have been too young to occupy all the soil. If the benefit from tillage were only to the water supply, the cultivated trees should become enough larger than those in sod to transpire as much water as would be transpired from the smaller trees in sod and from the grass; and there should then be little difference in the appearance and vigor of the trees; the cultivated trees should make no further gain over those in sod. Yet it is well known that, as long as trees are in sod, they continue to have leaves of a less intense green, to make less growth, and generally to show reduced vigor as compared with cultivated trees that are enough the larger to use much the more water. There is other evidence that not all of the reduction in growth and general vigor of trees in sod is due to a reduction in the water supply. Pickering (682) and Gourley (611) found great reduction in vigor caused by sod when the moisture content of the soil was not reduced.

Pickering conducted some exceptionally interesting experiments showing injurious effects of grass on trees; such as great reduction in growth, small, yellow, sickly foliage, and, in the case of trees old enough to bear, reduced yield of fruit. Most of his work was done with young trees, though he reports experiments also with old bearing trees. In the case of some very deep soils, the injurious effects of the grass were slight. There seemed to be no differences in the effect of the grass on different varieties of a species. Cherry trees seemed to be injured slightly less than were pear, apple, or plum trees. Possibly different results might have been obtained with older trees of these fruits.

Pickering early came to the conclusion that the injurious effect of grass is not to be explained by its effect on the moisture supply alone. He observed that the effect of grass on the trees is seen as a yellowing of the leaves, but without apparent wilting, whereas with serious water shortage there is wilting of the leaves. Further, in a dry year grass suffers worse than trees; yet the trees show this ill effect of grass when the grass shows no sign of suffering for moisture. It is, therefore, hard to see how, if the ill effect of grass on trees results from its effect on the water supply, grass should fail to show any effects of insufficient water supply. Further, his results do not indicate any greater ill effect of grass in dry years than in years of more abundant rainfall. Here, however, his results are not in agreement with those of Woodbury, Oskamp, and Noyes (736), who found the greatest ill effect of grass in the dry years. His results generally agree with those of Hedrick (623) and with Woodbury *et al.*, in that during the growing season the moisture supply under grass is less than in tilled soil. However, in some plots where the moisture content was as high under grass as with tillage, and in others where he took the precaution of increasing the water supply in the grass plots to above that in the tilled plots, he still found the characteristic injurious effects of grass; though the increased water supply was beneficial to the trees. The effect of the grass on aeration of the soil was also studied; when the soil was aerated artificially, by means of holes filled with stones, the ill effect of the grass was still to be seen.

Aside from its effect on moisture supply the explanation of the effect of grass that would seem most plausible would be that it might cause a reduction of mineral nutrient supply. Pickering seemed to find, however, that while an addition of mineral nutrients may benefit the trees growing in grass, it does not entirely obliterate the injurious effects of grass. With one plot of dwarf apple trees half of those in grass received heavy dressings of manure. The relative growth, measured as increase in weight, assigning to the tilled trees the value of 100, was 15 for grassed trees and 50 for those with grass and manure. The manure was beneficial, but did not completely offset the effect of the grass. Of course, it is possible that larger quantities of manure might have brought the growth of the tree in grass up to that of cultivated trees. In some pot experiments, trees were grown in earth alone; earth and grass; earth and grass, but with the grass roots separated from the tree roots by a layer of copper gauze; and earth with grass above the gauze and nutrients supplied in the water to the earth beneath the gauze. The relative increases in weight of the trees were respectively 100, 24, 20, and 23. Other experiments gave similar results except that the injury of the grass was not always as great.

Pickering reached the conclusion that there is excreted from the grass roots a substance that is toxic to the trees. Before discussing this theory, it seems well to examine the results of some other experiments with the effect of sod on trees.

Hedrick (623, 624) conducted two experiments concerning the effect of grass on trees, the grass being cut and left where it fell. By far the more dependable experiment was conducted in the Auchter orchard near Rochester, New York, with trees planted in 1877, the experiment beginning in 1903. The soil in the higher ground was a Dunkirk sandy loam to a depth of nine or ten inches, while that in the lower ground was a dark-colored Dunkirk loam to a depth of about twelve inches. Both types of surface soil were underlain by a fine compact sand that was coarser at a depth of about three feet. The sod during the first year consisted of a fairly equal division of timothy, orchard grass, and blue grass. The orchard grass, however, during succeeding years increased in quantity until little was left of any other grass. The grass was mowed twice in some years and once in others, and was left on the ground where it fell. According to Hedrick, there was sufficient grass to amount to two tons of hay to the acre. In all cases the tillage was thorough, and it began as early as April 11th in one year and as late as June 7th in another; in a majority of years it began after blooming time. There were some changes at the end of five years, the different treatments being indicated in Table 22, in which is given the yield during the last five years of the experiment.

TABLE 22. EFFECT OF CULTIVATION, OF SOD AND OF SOD WITH APPLICATIONS OF NITROGEN, ON THE YIELD OF BALDWIN APPLE TREES

TREATMENT	1909	1910	1911	1912	1913	AVERAGE
	Yield to the tree (bbls.)	Yield to the tree (bbls.)	Yield to the tree (bbls.)	Yield to the tree (bbls.)	Yield to the tree (bbls.)	Yield to the tree (bbls.)
Sod first 5 years, cultivated last 5 years (57 trees)	2.30	4.0	8.40	4.4	7.00	5.17
Cultivated 10 years (62–60 trees)	6.30	1.9	4.10	7.8	5.10	5.03
Sod 10 years (15 trees)	1.60	1.7	.17	3.6	2.50	1.92
Cultivated first 5 years, sod last 5 years (10 trees)	.73	1.3	.43	3.4	1.23	1.41
Sod 10 years, sodium nitrate last 5 years (28 trees)	3.00	3.9	.54	8.1	4.20	3.90
Cultivated first 5 years; sod last 5 years, sodium nitrate 350 pounds to the acre (30 trees)	.66	2.2	.72	5.7	3.00	2.46
Sod 10 years (18 trees)	2.50	1.4	.22	3.8	5.80	2.73
Cultivated first 5 years, sod last 5 years (19 trees)	.75	3.4	.33	5.9	2.59	2.59

Increased yield followed at once upon changing from sod to tillage; and, upon changing from tillage to sod, the reduced yield and vigor of the trees were marked, the deterioration in every way beginning during the first season. In two years of the experiment, moisture determinations were made about twice a week during July and August. Except when the rainfall was abundant, the moisture content in the tilled soil was much above that in the sod soil. Since there was this large difference in the moisture supply under tillage and sod, and since the application of nitrogen did not bring the yield of trees in sod up to that of tilled trees, Hedrick is inclined to conclude that the reduced yield in sod is due to the reduced water supply. This conclusion is further strengthened by the fact that the Auchter orchard is in a section of New York where the rainfall tends to be rather low; and Hedrick says that the trees in this orchard plainly suffered for water during almost every year. It is probable that more water was evaporated from this orchard-grass sod than would be evaporated from the grass in the average sod orchard; for the growth was luxuriant. The water supply to the trees may have been further reduced by the nature of the root growth in sod, which according to Hedrick was more shallow than that under tillage. In the cultivated plats there were more roots able to obtain moisture from rather great soil depths.

However, while the water supply was greatly reduced, not all of the injury to the trees was from reduced water supply; for application of nitrogen to the trees in sod greatly benefited them as to both yield and growth. Yet in this same orchard Collison (587) found no response whatever made by cultivated trees to applications of nitrogen. In some way, then, the grass reduced the supply of available nitrogen. The fruit was much larger on the tilled plats. The weight of an average apple was, for trees with tillage, 7.04 ounces, and for trees in sod, 5.01 ounces. Of course, the fruit ripened earlier and was more highly colored on the sod plats. Contrary to what had previously been expected, the bloom was heavier on the tilled trees. Yet with these tilled trees growth was markedly the greater; thus, during the first five years the average annual twig growth was, for trees with tillage, 6.7 inches and for trees in sod, 3.4 inches, and the average gain in trunk diameter during the ten years was, for trees with tillage, 3.9 inches, and for trees in sod, 2.39 inches.

Hedrick conducted experiments with tillage and sod mulch, also, in the Hitchings orchard near Syracuse, New York, where the soil was very deep and gravelly, where there was a large moisture supply from the higher adjacent land, and where the average rainfall was considerably greater than that at Rochester. The plats were not very uniform and conditions were not favorable for accurate experimental work. There were very slight differences in results with the sod mulch and with tilled plats. Whether the greater rainfall and the seepage water supplied to the trees was enough to prevent the sod from being injurious to the tree, or whether the possible excess water supply was as injurious to the tilled plats as the sod was to the others, it is not possible to say.

Stewart (710) found trees in sod to show striking response to applications of nitrogen; and, in southeastern Ohio, Ballou (561) obtained fully as high yields of apples in sod with applications of sodium nitrate as he obtained by tillage and sodium nitrate; though without the application of nitrogen the trees in sod yielded less than the unfertilized tilled trees. The average annual yields to the acre during five years were, for cultivation alone, 53.2; cultivation and sodium nitrate, 73.5; grass mulch, 37.6; grass mulch and sodium nitrate, 75.4 barrels. It appears that in this orchard the injurious effect of the sod was due entirely to its reduction of the supply of available nitrogen. In a number of other orchards, Ballou found as striking benefits from the use of readily available nitrogen in a sod orchard.

Gourley and Shunk (614) found sod to cause a very great reduction in the amount of available nitrogen in the soil. Thus, in a plat having cultivation and cover-crop the average number of parts to the million of nitrates in the dry soil through the season was from 18.75 to 41.26, while in the sod plat it was from 2.09 to 4.41. Gourley (612) found in this same orchard a great reduction in yield resulting from sod, though moisture determinations at intervals of three to four days from May to October during four years showed that at practically all times the moisture content in the sod plats was as great as that in the tilled plats. It seems probable, therefore, that in this orchard the grass injured the trees not by reducing the water supply, but rather by reducing the supply of available nitrogen.

Lyon, Heinicke, and Wilson (664) planted McIntosh apple trees, one year old cut back to six inches in height, in a soil, originally classified as Dunkirk clay loam, that was tile-drained and had had very uniform treatment. The trees were four feet apart each way and were left in the planting during four seasons, in the first of which all were cultivated alike. Beginning with the second season four plats of twenty trees each received the treatment indicated in Table 23, in which is also given, for the summer of 1920, the moisture content of the soil, during the months when it is low, June and July, and the amount of nitrate nitrogen in pounds to the acre.

The supply of nitrate nitrogen was greatly reduced by the timothy. The water supply also was reduced for the months of June and July. Growth of the trees was greatly reduced. It is interesting to note that, although slightly the greater reduction in the water supply by sod was in the plats receiving 900 pounds of sodium nitrate to the acre, trees in these plats made much more growth than was made by trees in sod to which no nitrate was applied or by trees to which only 100 to 300 pounds of nitrate was applied to an acre. The reduced water supply seems to have been less important in checking growth than was the reduced nitrate supply. In the year 1920 nitrate nitrogen seemed to be lower in the cultivated plats receiving no nitrogen than in the sod plats receiving 900 pounds of sodium nitrate to an acre; although trees in the cultivated plats made the greater growth. However, in 1919 the average nitrate-nitrogen con-

TABLE 23. SHOWING EFFECT OF SOD ON GROWTH OF APPLE TREES AND ON MOISTURE AND NITRATE NITROGEN IN THE SOIL

TREATMENT	AVERAGE WEIGHT OF TREES (grams)	POUNDS OF NITRATE NITROGEN TO THE ACRE						MOISTURE CONTENT PERCENTAGE OF DRY SOIL, TOP EIGHT INCHES					
		April 13	May 18	June 11	June 29	July 15	Oct. 28	April 13	May 18	June 11	June 29	July 15	Oct. 28
Sod	1404±73	3.1	2.3	2.0	2.7	2.2	0.0	25.4	24.0	15.9	12.8	15.1	24.7
Cultivation and cover-crop	4703±30	3.7	5.4	5.6	13.3	9.5	0.0	25.4	22.3	19.0	16.7	16.9	20.2
Sod and 100 lbs. $NaNO_3$	1328±91	4.5	3.1	2.0	3.4	2.4	trace	25.4	23.3	15.0	12.2	14.7	24.6
Cultivation and cover-crop and 100 lbs. $NaNO_3$	4861±134	3.8	11.6	14.4	24.7	25.3	0.0	24.4	21.9	19.3	17.4	17.6	19.5
Sod and 300 lbs. $NaNO_3$	1602±130	6.3	5.1	1.6	3.8	6.3	0.0	25.8	23.9	14.2	11.3	14.0	24.4
Cultivation and cover-crop and 300 lbs. $NaNO_3$	5023±132	6.3	28.2	20.5	51.1	58.1	trace	24.8	22.6	19.3	17.4	18.0	18.9
Sod and 900 lbs. $NaNO_3$	3054±251	4.8	47.9	25.4	17.0	11.6	1.1	24.9	23.8	13.1	11.3	14.3	20.7
Cultivation and cover-crop and 900 lbs. $NaNO_3$	5014±78	4.8	50.8	60.8	100.9	146.5	5.8	24.6	22.2	19.8	18.0	18.3	18.1

tent in the sod plats receiving 900 pounds of sodium nitrate was, for April 22d, 3.5; for July 8th, 11.4; for August 15th, 14.0; and for October 11th, 10.0 pounds to the acre, while that for the cultivated plats receiving no nitrate was, for April 22d, 3.9; July 8th, 40.0; August 15th, 37.1; and for October 11th, 26.9 pounds to the acre. In other words, during 1919 the application of 900 pounds to the acre of sodium nitrate to the sod soil did not bring the supply of available nitrogen nearly up to that in the same type of soil under cultivation and cover-crop with no nitrate applied. Unfortunately, in that year nitrate determinations were not made in May or June. In 1919 the moisture supply in the sod plats was slightly lower during July than in the cultivated plats; but the reverse was true during August. These data suggest even more strongly than do those of 1920 that in this soil sod reduced the growth of the trees much more largely through a reduction in the supply of available nitrogen than through its influence on the water supply.

While these results indicate that much of the injury to trees by grass may be due to the influence of the grass on the supply of nitrate nitrogen, they do not prove conclusively that there may not have been also a toxic effect such as Pickering describes, or that some of the injury may not have resulted from a reduced oxygen supply as Clements (408) suggests. The evidence is not conclusive that, in the case of the sod trees receiving 900 pounds of sodium nitrate to an acre, the nitrogen supply was not as large as apple trees would require in order to make optimum growth; and there is no conclusive proof that the reduction in the water supply was great enough to reduce growth to the extent that it was reduced even in the best sod plats. On the other hand, there is no conclusive proof that any of the reduction in growth caused by sod was due to a toxic substance or that all of the reduction in growth caused by the timothy may not have been due to reduction in the nitrate nitrogen and in the water supply.

How grass reduces the supply of nitrate nitrogen. It would be expected that the grass in its growth would use a part of the supply of available nitrogen, but after a few years the decaying grass left on the ground should replace much of this. However, it seems that the supply of nitrate nitrogen may be reduced by the grass much more rapidly than it should be reduced if the only difference in the nitrate-nitrogen supply between sod and tillage were a difference in the amount of nitrogen taken out by the plants. Bizzell (568) found total nitrogen higher in land where timothy had been cut and removed from the soil for a number of years than in cultivated land; though during the summer months the supply of nitrate nitrogen was much the larger in the cultivated land. It seems that sod reduces the supply of nitrate nitrogen, but conserves the supply of total nitrogen. Different crops influence differently the supply of nitrogen in the soil.

Lyon and Bizzell (662) seemed to find that reduction of the available nitrate supply in the soil by grass is greater than the amount used by the grass, nitrate formation under grass being very much slower than under certain other crops, such as maize. Thus, while under no crop the nitrate supply was many times greater than under timothy, under maize it was often somewhat higher during the early growth of the crop than in soil where no crop was used. It would seem that maize might use nearly as much nitrate nitrogen as would timothy. Bizzell (568) found that the reduction in nitrate nitrogen under timothy may be as large as or larger than the amount removed by the crop when a large quantity of sodium nitrate has been applied. In some plats of timothy sod in a Dunkirk clay loam to which nitrogen was applied in the spring, when to the amount of nitrogen applied was added the amount of nitrate that would have been formed between April 25th and July 12th and from this was deducted the amount of nitrogen in the soil July 12th plus one and one third times the amount of nitrogen in the crop (assuming that the new roots and stubble would contain one third as much as the crop would contain), there would still be an apparent disappearance of nitrate nitrogen to the extent of 51.18 pounds of nitrogen to the acre. Studies of drainage water from soil of this type in tanks (lysimetres) indicated that, at most, not more than one or two pounds of nitrogen could have leached away; and other studies indicated that only a very few pounds could have moved downward into soil below the depth of eight inches (that to which the soil was analyzed). He thinks that under sod the nitrates are used by the soil organisms and are thus transformed to ammonia or to some organic combination. There is strong evidence that non-nitrogenous organic matter in the soil may reduce the supply of available nitrogen. Koch (650) found that cellulose, resins, and other organic materials when added to the soil may be used as food by organisms, thus increasing their growth, and, therefore, their use of the soil nitrates, which in the organisms are combined in complex organic compounds such as albuminoids. Until the organisms die and become decomposed, this nitrogen is not available for higher plants. After the supply of organic material is reduced to the normal, nitrates will again begin to accumulate and plants will grow in the soil as well as before the addition of organic matter, or better. Murray (678), having observed that wheat crops are better if the straw of the previous crop is burned than if it is ploughed under, studied the effect of straw on nitrogen changes in the soil. He found that straw in the soil causes a great reduction in nitrate nitrogen, but not in total nitrogen. Yet such organic matter did not seem to inhibit the growth of nitrifying bacteria. After the straw had been incorporated in the soil for a time, there was a rather large increase in the number of bacteria in the soil. Murray thinks that the straw furnishes food for the growth of bacteria and that these use the nitrate and even ammonium sulphate as a source of nitrogen. As the bacteria die, the nitrogen is left in organic combination and is not available for the plants until the compounds undergo decomposition.

Albrecht (549) found that a straw mulch on the surface of the soil tends to have a similar effect. Lyon (661) found a straw mulch to reduce the supply of nitrate nitrogen, though it increased the growth of maize. Gibbs and Werkman (605) found that tree products, such as sawdust or the collection of material that covers the ground in a forest, when incorporated in the soil, reduce the amount of nitrate accumulation. It is possible that there may be in some wood materials substances toxic to the nitrifying organisms; for the products of different species of trees reduced nitrate accumulation in different degrees. However, the differences may be due to difference in the influence on other soil organisms. Koch (650) found that tannin in some woods may encourage the growth of fungi in the soil and thus reduce the nitrate supply.

If plants should be found to excrete into the soil rather large quantities of non-nitrogenous organic matter, the explanation of the large reduction of soil nitrates by sod might be that this organic matter, being available for energy, increases the growth of soil organisms and that these use nitrate nitrogen and leave it temporarily in organic combination. Lyon and Wilson (665) found that plants grown with the roots in a sterile nutrient solution excreted rather large quantities of organic matter into the medium; and Wilson (735) found that exudate water from plant leaves contained much organic material and was a good medium for the growth of bacteria. Woodbury, Oskamp, and Noyes (736) seemed to find larger numbers of bacteria in soil under sod than in cultivated soil; and Pickering (682) found more than three times as many bacteria in grass soil as in cultivated soil.

If it is true that the reduction in available nitrogen under sod is caused by excretion of organic substances that increase the growth of soil organisms, then Pickering's evidence concerning the excretion of toxic substances by the grass that injure the tree is not very conclusive. He assumed that, when he prevented the grass roots from coming into competition with the tree roots, he prevented the sod from influencing the nitrogen supply. However, it seems probable that organic matter excreted from the grass roots might leach through the gauze into the soil surrounding the tree roots and stimulate the growth of soil organisms, which would use the nitrate nitrogen. Heinicke (627) seemed to find this to happen. He planted apple grafts closely in a field, covering the soil of a part of them with thin cloth dipped in paraffin, there being small holes through which water could pass. Over a part of this he placed sod, and over the remainder, soil or sand. He found that under such field conditions the sod injured the trees. However, nitrate nitrogen was reduced in the soil under the grass during the first year; and when, during the next year, he put the soil where the grass had been and the grass where the soil had been, nitrate nitrogen was lowered in the soil under the newly placed grass. In other words, the same soil was the lower in nitrate nitrogen in the year when it was under grass and the higher in nitrate nitrogen in the year when it was under soil or sand. Examination showed that the grass roots did not grow through the paraffined cloth. Some influence from the grass reduced the supply of nitrate nitrogen in the soil below. It seems probable either that organic matter liberated from the grass roots passed through the small holes and caused an increased growth of soil organism and an increased use of nitrate nitrogen in the soil under the paraffined cloth, or that nitrates are formed mainly in the surface few inches and that the grass prevented the formation and leaching downward of nitrates. And Pickering's results, with which sod in trays upon the soil of potted trees injured the trees, may be explained in the same way. He analyzed the soil in which some of these trees had been injured by growing under grass and that in which there had been no grass influence and found as much "soluble" nitrogen in the former as in the latter. However, there are two possible defects in these results. First, ammonia seems to have been included as soluble nitrogen. Second, after the grass and trees were removed from the soil, it is possible that nitrification proceeded rapidly and the supply of nitrate nitrogen may have been much above that in the soil while the trees were in it.

There is left little or no evidence that grass roots liberate a toxic substance that injures the trees. On the other hand, there is hardly conclusive proof that such a toxic substance is not liberated. It seems reasonably certain, however, that the injurious effect of grass on trees is due almost entirely, if not entirely, to its reduction of the supply of nitrate nitrogen and of water. And it seems that under most conditions much the greater injury is from the reduction of nitrate nitrogen. Certainly the most promising means of reducing the injury to the trees caused by sod is by the rather liberal application of readily available nitrogen.

The place of sod in orchard practice. From the experimental evidence available, it seems certain that, considering not merely the first few bearing years, but rather the bearing of a mature orchard, sod, even when accompanied with large annual applications of nitrogen, may be expected to reduce the growth and yield of trees. However, with some fruits, as apples and pears, good results can be obtained in sod orchards if available nitrogen is applied. And the acre cost of soil management, including the application of nitrogen, is generally found to be less than the cost of cultivation and an annual cover-crop. Generally the larger yields will cause the cultivated orchard to be the more profitable, but there are conditions under which the sod is the more desirable. Thus, in hilly land cultivation is very expensive and, as in the case of the land in southern Ohio described by Ballou, tillage may cause serious washing of the soil. Stony land may grow good trees, but ploughing it may be very expensive. Trees in sod may make better growth in wet land than will cultivated trees, provided the sod is of a kind like Kentucky blue grass that starts growth very early in the spring. Thus, I have been able to cause striking improvement in the growth of apple, pear, plum, and cherry trees in a wet, heavy clay soil in a city lot at Ithaca, New York, by establishing a sod of Kentucky blue grass closely around them. The trees would make almost no growth during the years the soil was worked, but made an excellent growth during the first year of the sod. Sodium nitrate was applied to the cultivated soil as well as to the sod. Not all of these trees were changed to sod in the same year, and it is certain that the improvement in growth was not due to differences in the seasons. In the sod the roots that grow along the surface of the soil where aeration is best are not cut. The transpiration from the grass must keep the water table a little lower in the soil during early summer. It is probable that in locations where, because of the contour of the land or of the texture of the soil, tile drainage gives only imperfect results, trees will make better growth in sod than with tillage; provided nitrate nitrogen is applied annually. However, this effect would be expected only in soils with the water table very near the surface. Pickering seemed to find greater injury from sod at Ridgemont, where there is an impervious layer rather near the surface of the soil, than at Harpenden where root growth, in some cases at least, is deeper. The results were not uniform, however; and grassing practices and fruit varieties used were not always the same in the two locations. Some observations in New York suggest that, without applications of available nitrogen, sod is less injurious in deep well-drained soils than in medium shallow soils.

Yet Maney and Plagge (232) found blue grass sod very injurious to apple trees in the deep loess soil in southwestern Iowa; and we have seen that, working in a rather deep soil, Ballou found similar results, except when he applied soluble nitrogen annually. The use of nitrogen with such deep soils, however, seemed to bring the trees up to a yield and growth as great as that of cultivated trees having an abundance of available nitrogen. The experiences of Hedrick and of Lyon, Heinicke, and Wilson in New York suggest that in those heavier and more shallow soils it is not possible by application of nitrogen to bring yield and growth of trees in sod up to that of cultivated trees. It seems possible that, in so far as sod injures the trees through its reduction of the water supply, the injury will be less in the deep, well-drained soil, but that, in so far as the injury is due to the effect of the grass on the nitrate-nitrogen supply, depth of soil may make little difference.

There may be, in a few cases, soils in which trees make such vigorous growth that, during a few years after they have reached bearing age, either sod with annual applications of nitrogen or strips of sod may be desirable in order to check growth and throw them into fruiting. Thus, Pickering (682) found strips of grass to increase the yield of dwarf apple trees during the first ten years in the orchard, although growth was checked. He does not give records of the behavior of these trees when they were older. With standard trees planted at the distances from each other that is common in American orchards, it is seldom profitable to check the growth of young trees in order to cause them to begin bearing younger; for reduction in later yield due to reduction in the size of the tree will offset the early gain.

Pickering studied the effect of eighteen different grasses on the trees and found the injury greater in proportion as the growth of the grass was stronger. He studied the effects of clovers also and found them as injurious as the fine-textured, weak-growing grasses. Yet some growers seem to have excellent success by sowing clover as a cover-crop in midsummer and leaving it to grow during the following summer. The orchard is thus in clover sod during every other year. By this means the supply of humus can be maintained very high; for large quantities of material may be worked into the soil at the ploughing following the summer in clover sod. The soil can thus be kept in excellent tilth. Whether or not the growth and yield of the tree will be reduced by the year in clover sod, and, if it is reduced, whether or not the reduction is more than enough to offset the reduced cost of tillage, it is not possible to say. Further, while Pickering seemed to find clover growing around young trees to be injurious, Maney and Plagge (232) found apple trees in southwestern Iowa growing in clover sod — the clover being cut and left on the ground — to make as large growth and to yield as well as those in cultivation; although, in the same orchard, a grass sod was very injurious. Stewart (709) had exceptionally good results from the use of alfalfa grown among young trees, enough of the hay being piled around the trees to prevent growth of alfalfa over the roots. Browne (580) working in Oregon found good results from using alfalfa among young trees, even when the hay was removed. The soil, however, was disked in the spring and irrigation was practiced. Growers in many sections report good results from using alfalfa in the orchard. However, both alfalfa as a continuous cover and clover in every other summer may be desirable for non-irrigation sections only in soils where tree roots may come to be very deep and extensive, so that fluctuations in the water and perhaps the nitrogen supply to the top may be reduced. Both crops evaporate large quantities of water, and in some soils both reduce the available nitrogen supply during early summer in spite of their ability to fix free nitrogen. Lyon and Bizzell (662) have shown that this is true of alfalfa, nitrate nitrogen under this crop being far below that in a bare soil. However, it may be that under most conditions clover and alfalfa do not reduce the nitrate supply through the summer seriously enough to injure apple or pear trees; and in some orchards, such as many in California, the soil supply of available nitrogen may be so great that, even with peaches or cherries, alfalfa or some other leguminous crop may be grown without injury to the trees, provided the water supply is adequate. However, Batchelor (563a) seemed to find strips of alfalfa thirty feet wide between Persian Walnut trees sixty feet apart to cause a rather large reduction in yield of the walnut trees, although an exceptionally large supply of irrigation water was used. He thinks that the reduction in yield was due to a reduction in the nitrate-nitrogen supply under the alfalfa. The alfalfa was harvested. While normally in a soil rather rich in total nitrogen the nitrate-nitrogen supply under growing alfalfa is less than that in a cultivated soil, Brown (580) seemed to find that, in the Hood Silt soil low in nitrogen, growing alfalfa continuously but leaving it on the soil in the orchard improved the nitrate supply, as compared with that in plats in continuous clean cultivation and not fertilized with nitrogen.

Ballou (561) found that the application of phosphorus to the orchard soils in southeastern Ohio would tend to cause clovers to predominate in the sod. His table indicates that this use of phosphorus alone in some way, perhaps because of the substitution of clover for other grasses, greatly increased the yield of the trees. However, he suggests that, since there were no buffer rows, the roots of the trees in this plat probably extended into the adjacent plats on which sodium nitrate was applied.

He emphasizes the importance of a good growth of grass in the sod orchard in order that, as it dies, it will form a thick mulch. Such a mulch might reduce the amount of soil erosion; but it is doubtful if it would conserve more moisture than would be transpired from the grass that formed it. However, it might, by preventing the growth of other plants and by protecting the soil from the wind, conserve moisture in late summer after the grass had died down.

Mulching trees. Hedrick (623, 624) uses the term "sod mulch" as applying to a system in which, beginning with the young orchard, the grass is cut and piled around the trees in an area a little greater than the spread of the branches each year until the trees are so large that the roots spread through all of the land, when it is left where it falls. Green and Ballou (614a), on the other hand, use the same term as applying to a system in which the trees are heavily mulched with straw and the grass is cut and piled around the trees, thus adding the grass to the straw mulch. In this discussion the term "mulch" will be used as applying to a layer of vegetable material thick enough to prevent the growth of weeds and grass or at least to permit only slight growth of either.

Such a mulch would be expected to conserve moisture very effectively; for not only does it reduce to the minimum evaporation from the surface of the soil, but it prevents the growth of plants that would transpire large quantities of water. Woodbury, Oskamp, and Noyes (736) found the moisture precentage of a soil under a mulch continuously higher through the summer than that of the soil with cultivation and a cover-crop; and Albrecht (549) found a mulch on uncropped soil to keep it too wet for good tilth.

We have seen that Albrecht found the supply of nitrate nitrogen low under a mulch. Woodbury, Oskamp, and Noyes also seemed to find nitrate nitrogen lower under a mulch than in cultivated soil though much higher than under sod. The supply of nitrate nitrogen seemed to be much higher under the mulch used by these workers than under the mulch used by Albrecht. It is not clear what the cause of this difference may have been. The soil with which Albrecht worked remained too wet for good tilth, while that of Woodbury *et al.* was not so wet, the difference probably being due to the water removed by the trees around which the mulch was placed. However, I know of no conclusive proof that this difference in nearness to moisture saturation would influence the amount of nitrate nitrogen.

Green and Ballou (614a) found the growth and yield of young apple trees greater with mulch culture than with tillage and a cover-crop. Stewart (710) found yield and growth of young mulched trees equal to that of trees under tillage or slightly greater. With old trees the results are somewhat irregular; but yields of mulched trees seem to be about equal to the yields of trees having tillage; while the tilled trees tend to make the larger growth. Woodbury *et al.* found the growth of apple trees during the first eight years in the orchard about the same with tillage and cover-crop as with straw mulch, though later (Greene, 616) the cultivated trees made the better growth and yielded the more fruit.

It is possible that this vigorous growth of mulched trees is made because of the abundant water supply and that it would surpass that of cultivated trees except for the reduction in nitrate nitrogen caused by the mulch. However, mulched trees do not seem to have the pale green or yellowish leaves and light red twigs characteristic of nitrogen starvation that is generally to be observed with unfertilized trees in sod. It may be that in these soils the supply of nitrate nitrogen under a mulch, though lower than in the same soils under cultivation, is adequate for good growth of apple trees; and with other kinds, such as the peach, the results might be different. Stewart (709) found the best growth of young trees when he used a mulch formed by piling alfalfa around them. It is possible that with this mulch the supply of nitrate nitrogen is larger than with a straw mulch. Ballou (561) found the yield of apple trees to which were applied annually five pounds of sodium nitrate and a bale of straw about the same as that of trees to which was applied annually ten pounds of sodium nitrate. This result suggests, but does not prove, that a bale of straw as mulch was as beneficial as five pounds of sodium nitrate. It is possible that five pounds of sodium nitrate furnished an adequate supply of nitrate-nitrogen for these trees and that the mulch had little influence. However, if the mulch greatly reduced the growth of grass it should have increased the supply of nitrate nitrogen and of water for the trees in sod.

The fact that in the work of Woodbury *et al.* the mulch seemed to be less effective with older trees than with younger ones may have been due to a greater nitrogen requirement of older trees; but the evidence is not convincing that, in the experiments cited, the annual increase in spread of the mulch was as great as the increase in spread of the tree roots or that the mulch used with the older trees was as heavy as that used with the younger ones. However, it might be expected that the rather low nitrate-nitrogen supply under the mulch would be less harmful to young than to old trees. There must be a considerable nitrogen supply just under the mulch; and conditions seem to be favorable for the rapid extension of the root system. Green and Ballou (614a) seemed to find as extensive root systems deep in a mulched soil as at the same depths in a cultivated soil, and, in addition, great masses of roots just beneath the surface and just above the surface under the mulch. With this rapid extension of the absorbing system the young mulched trees might have obtained an adequate nitrogen supply as well as an exceptional water supply even though the concentration of nitrate nitrogen in the soil was rather low. With old trees the roots would have penetrated all available soil so that there would have been no new source of nitrate nitrogen into which the roots could grow. The transpiring leaf surface and the nitrogen requirement would then be so large that the water conserved by the mulch or the nitrogen supply from the decaying material at the surface of the soil might be insignificant compared with the reduced nitrate nitrogen supply in the soil.

The use of a heavy mulch in orchard practice has as yet not been very great. In but few sections is there material available for such a mulch except as it can be grown between the trees in the case of young orchards. The desirability of mulch culture and of sod culture is somewhat reduced by the greater danger of injury to the trees by mice and by fire.

Cover-crops for the orchard. By a cover-crop is meant a crop grown in the orchard, generally in late summer after cultivation has ceased, to be ploughed under for the benefit of the soil. The use of a cover-crop in this way helps to maintain the nitrogen supply, since nitrogen that would be lost from the soil is thus used and returned to the soil when the cover-crop is ploughed under. Further, if it be a leguminous crop, nitrogen is added by fixation. The decomposition of this material in the soil may tend to render certain other mineral nutrients more available for the plant. It also renders the soil more friable and, as we have seen in a previous chapter, increases the water holding capacity of the soil.

The cover-crop may serve other useful purposes. As we have seen in Chapter 9, it may remove water from the soil and thus check growth and hasten maturity of fruit and wood; it may hasten maturity by reducing also the amount of nitrate nitrogen in the soil during late summer. Hastening maturity of fruit may or may not be desirable. Hedrick (623) found that, in the climate of New York, Baldwin apples in a sod orchard were not as crisp and juicy as fruit of the same variety in a cultivated orchard, though early maturing fruits from the sod trees were the more highly colored. It is doubtful if the influence of the cover-crop alone would often be great enough appreciably to modify the texture of the fruit, though it might be great enough to cause slightly earlier maturity and therefore, in some cases, slightly better color and sometimes slightly better flavor.

The use of a cover-crop to hasten maturity of the wood may be desirable, particularly with young trees in climates where late growth may result in winter injury. In very cold climates, particularly if the soil is an open, sandy or gravelly one that freezes to a great depth, a cover-crop is desirable for preventing root freezing. The covering itself, and particularly with the snow it may hold, reduces the loss of heat by preventing the cold winds from blowing directly against the soil.

Under average conditions, however, the cover-crop is used for its effect on the available nutrient supply and for its effect on the physical condition of the soil. The view that the growing of a special cover-crop is profitable is generally accepted by writers and college teachers of pomology. However, among growers in the eastern and central parts of the United States the use of any cover-crop, other than the weeds that grow after cultivation ceases, is not so nearly universal as might be expected. Thus, of fifty fruit farms in an excellent fruit section in western New York, thirty had not had cover-crops during the five years ending with 1919, yet nearly all were cultivated orchards. Observation suggests that throughout New York not more than this percentage of the fruit growers plant a cover-crop in any year; and a much smaller percentage plant one every year.

Stewart (710) found no measurable injury to the tree from omitting the cover-crop during a considerable number of years; but later one of his continuous clean culture plats showed serious injury both to the soil and to the trees. The results obtained by Gourley (612) indicate that, where the orchard is cultivated, the use of a cover-crop is desirable, but that failure to plant one during two or three consecutive years may cause no measurable injury. On two adjacent plats, one was cultivated every two weeks until September with no cover-crop, and the other was cultivated until July 10th, when a cover-crop of crimson clover was sown. The yield was practically the same for the two plats during a period of ten years. The growth of the trees in the plat with no cover-crops declined slightly during the later years of the period; and the amount of nitrates in the soil was much lower, while the percentage of moisture in the soil was slightly lower. It should be borne in mind that, with the plat receiving no cover-crop, cultivation continued so late that there was little or no weed growth. If cultivation had ceased earlier in the summer so that weed growth might have been rather abundant, it seems probable that the nitrate content in this soil might have been more nearly equal to that in the plat where a cover-crop was used. Oskamp (679a) found in Indiana considerably better growth of apple trees during the fifth to the ninth year in the orchard when a strong growing cover-crop was sown in late July or early August than when the soil was cultivated late enough to prevent weed growth. In fact the growth of trees was considerably better with such strong growing cover-crops than when weeds were permitted to grow or weak cover-crops were used. In the main the best growth was made by the trees in the plats to which the largest amounts of dry matter and nitrogen was returned to the soil by the cover-crop. The soil had a very porous gravelly subsoil and it may be that the nitrates were quickly leached away and that clean cultivation throughout the season was more injurious than it would have been in a soil with a less porous subsoil.

Cover-crops for nitrogen fixation. McCue (667) found, under conditions in Delaware, that the cowpea and the soy bean are the best cover-crops for peaches. With one of these cover-crops used every year it was possible to maintain a satisfactory nitrogen supply. This was in a soil where peach trees will respond profitably to rather large applications of nitrogen. The experiment lasted from 1909 to 1917 inclusively, and the dates of sowing the crop ranged from July 28th to August 7th. Winter vetch planted at the same time made but little growth before it was ploughed under in the spring. Mammoth clover was a failure under his soil conditions. Crimson clover, while apparently making better growth and giving better results than it does under average soil conditions, was well below the cowpea in its effect on the fruiting of the trees. Not only was the vigor of the tree, as indicated by yield, influenced by the cowpea, but the maturity of the fruit was appreciably delayed, the delay being greater the longer the experiment was continued. This was probably largely a result of the nitrogen supplied. The soy bean plat and the plat having a cover-crop of rye and crimson clover showed this effect, but to a smaller extent. Naturally the color of the fruit was reduced by the use of cover-crops. With the cowpea there was indication that this reduction in color would soon be so great as appreciably to reduce the market value of the fruit. In such a case, of course, the remedy would be to omit the use of a leguminous cover-crop for a year or two. It seems certain then that in regions where the cowpea and the soy bean do well an abundant supply of nitrogen for the orchard can be maintained by using these plants as cover-crops. It should be mentioned, however, that Picket (684) in Illinois seemed to find the use of the cowpea as a cover-crop to check the growth and reduce the fruiting of peach trees up to four years of age. However, his peach trees were growing in a rather shallow soil over a tight clay subsoil. Crane (591a) seemed to find that, in a soil very poorly retentive of moisture, a leguminous cover-crop, grown during the development of the fruit, increased the amount of annual growth, but reduced the size of the fruit, perhaps by reducing the water supply.

For sections in latitudes too high for these crops to thrive, there is no known leguminous cover-crop that, sown as late as August 1, will furnish enough nitrogen greatly to increase the vigor of the trees. With leguminous crops such as vetch and the clovers that can be grown in short cool summers, the seed are generally rather expensive; and unless the cover-crop can be sown as early as July 15th or earlier, it is doubtful if enough nitrogen will be furnished to justify the expenditure. In many cases it may be more profitable to use a cheaper cover-crop, such as rape or buckwheat, and to buy nitrogen in the form of sodium nitrate. Rape or buckwheat making good growth might maintain a higher nitrogen content in the soil than vetch making but little growth, since any crop ploughed under returns to the soil nitrogen that would be lost if no crop had been growing on it.

Over-wintering or other cover-crops. Some cover-crops, such as clover, winter vetch, and rye, live through the winter and continue growth in the spring. In sections where root freezing is serious, this may be an advantage through its furnishing the soil with a better winter cover and thus preventing such deep freezing. However, good growth of rape or cow-horn turnips, even though it be killed in early winter, may furnish more cover than will a weak growth of an over-wintering crop. Probably the greatest benefit from an over-wintering cover-crop is the effect it has on the physical condition of the soil in the spring. The cover-crop growing in the spring seems to remove excess water; at any rate, the soil is generally in much better tilth at spring ploughing time when such a cover-crop is used. The disadvantage of the over-winter crop is that if it is not ploughed under very early it may be injurious to the trees. This is particularly true of a non-leguminous crop, such as rye.

We have seen that incorporating in the soil vegetable material such as straw may injure the succeeding crop of fruit by reducing the supply of nitrate nitrogen. Martin (673) found that the more mature vegetable material is when it is incorporated in the soil the more slowly it decomposes and the more slowly nitrates accumulate. The most rapid decomposition, the most rapid accumulation of nitrate nitrogen and the greatest benefit to the soil, as measured by improved crop growth, results when the green manure is incorporated in the soil in the most succulent stage; when it is about half grown. He found also that nitrates did not begin to accumulate in the soil until the cover-crop ploughed under had been considerably decomposed. From these results it seems probable that, if a cover-crop reaches a rather mature dry condition before it is ploughed under in the spring, there may be such a delay in the spring formation of nitrates that growth of the trees, and perhaps the percentage of flowers to set fruit, may be reduced. However, this could happen only if spring ploughing were greatly delayed and perhaps only in a section where the soil nitrate supply tends to be very low in the spring. In some orchard districts in California where winters are mild and the rainfall low, there is not the low spring soil nitrate content that seems to be general in humid sections with considerable periods of freezing winter weather.

Some desirable cover-crops. With kinds used as cover-crops, unless there is wide difference in behavior, such as that between leguminous and non-leguminous crops as to nitrogen fixation, or that between over-wintering crops and crops that die in early winter, it is doubtful if their relative value can be measured by the effect on the trees. It seems better to study their general behavior and their effect on the soil, and if these are good to assume that the effect on the trees will be good. However, with fruits like the peach that are sensitive to changes in the water or nitrogen content of the soil, it may be possible by the effect on the trees to learn something at least as to the value of certain non-leguminous crops. Thus, McCue (667) found oats sown near the first of August injurious to peach trees; and Picket (683) seemed to find rye injurious to young peach trees. The value of a cover-crop, in so far as its effect on the soil is concerned, will be influenced by the climate and soil conditions in the orchard. For example, Dwarf Essex rape under open orchard conditions is one of the best cover-crops; particularly for clay soils in cool climates where the water supply is rather large. Yet McCue found in Delaware that after peach trees are large enough to shade the soil both rape and cowhorn turnips make a very poor growth. Under conditions prevailing in apple orchards in New York, rape generally makes good growth except in hot dry years. It makes an excellent winter cover and is one of the best of crops with which to put a heavy clay soil into friable condition. However, the leaves remain wet very late in the morning and it is therefore troublesome at picking time. This can be obviated by mowing just before picking time, after which it will make a considerable amount of new growth from sprouts formed at the base of the stalk; since it withstands much freezing and grows late into autumn. Four pounds of seed are enough for an acre; and these will generally cost only about fifteen to twenty cents a pound.

Buckwheat, also, is excellent for the soil, and the cost of the seed is small. Martin (673) found that buckwheat in mature stages decomposed much more rapidly in the soil than do rye and oats in the same stages of maturity. But it is killed by the first frost; and, unless the growth has been excellent, it forms only a very thin covering on the ground during winter. Oats and barley are grown rather cheaply and grow late into the autumn; but they do not supply a large amount of vegetable matter for the soil.

McCue found cowpeas to withstand the shade and the trampling necessary to pick the fruit and to make a good growth in Delaware orchards almost every year. At higher latitudes, winter vetch seems to have these qualities, except that it often fails to give a good stand. And the seed are expensive. One of the most popular cover-crops, in New York at least, is red clover. It puts the soil into excellent condition at ploughing time in the spring, and of course adds some nitrogen. However, unless it is sown early in summer or left until late in spring before being ploughed under it adds a rather small amount of vegetable matter to the soil. Further, the seed are rather expensive and in some soils liming and perhaps the use of phosphorus may be necessary in order to obtain a stand. Oskamp did not find clover to furnish much vegetable matter to the soil in Indiana.

Perhaps the most widely used practice as to cover-crops in orchards in the northeastern part of the United States is to encourage a growth of weeds in late summer and autumn. If cultivation ceases early enough in summer, a good growth of weeds will generally develop; and these ploughed under may keep the soil in good condition. Weeds may grow in the orchard, however, that are very troublesome at picking time. Another disadvantage of weeds, particularly if cultivation ceases in June, is that some forms such as foxtail (*Setaria glauca*) mature so early that, whether ploughing is in the spring or the fall, they will be dry and slow of decomposition when incorporated in the soil. In soils where rape does well a better plan than depending on weeds alone seems to be to sow the rape in early July. Generally a strong growth of weeds will be associated with the rape. If all of this growth is mowed before it reaches full maturity, there will be a late growth of sprouts from the rape stubs that, whether ploughing is in late fall or early spring, seems to be very effective in getting the soil into a good condition for tree growth. Certainly it is very effective in improving the tilth of a compact clay soil.

It should be emphasized that in Gourley's experiment, with the plat having clean cultivation without a cover-crop, tillage continued so late in summer that there was little if any growth of weeds. If cultivation had ceased by July 1st so that a heavy crop of weeds could have grown between the trees it is possible that the check in the growth of the trees by the end of five years may not have resulted. Then it is probable that, since the soil was practically bare in winter the leaves were blown across this into adjacent plats.

The importance of the leaves in supplying organic matter to the soil seems to have received little consideration. Yet it is doubtful if, at latitudes too high for successful growth of cowpeas, in the average orchard cultivated annually until August, a cover-crop can be depended upon to furnish as much organic matter as will be furnished by the leaves of trees large enough to occupy all available space in the orchard. Thus, Van Slyke *et al.* (722) found a Baldwin apple tree about thirty years old to have 49.7 pounds of dry matter in the leaves of a year in which the tree was bearing a rather heavy crop. We have seen, in Chapter 12, that a heavy crop greatly reduces the leaf surface in the year when the crop is borne, not only through a great reduction in shoot growth but also through a reduction in the size of both spur leaves and shoot leaves. It seems probable that in the non-bearing year the dry matter in the leaves of this tree must have been sixty-five to seventy-five pounds. If it required forty of these trees to occupy all of the available space in an acre, the dry matter in the leaves returned to the soil was two thousand pounds in the bearing year and probably three thousand pounds in the non-bearing year; about as much as Oskamp (679a) found to be supplied by an average cover-crop, even in a young orchard where much better cover-crop growth is made than in a mature orchard. At the Cornell Experiment Station a strong Baldwin or McIntosh apple tree ten years old was found to bear twenty to twenty-three pounds of dry matter in the leaves. In such an orchard planted with fillers so that the trees are twenty feet apart each way the leaves should return annually more than a ton of dry matter to an acre when the trees are ten to twelve years old, and probably larger quantities before the fillers would have to be cut out. Van Slyke found peach trees seven to nine years old to have as high as sixteen pounds of dry matter in the leaves and Thompson (714) found 20.5 pounds of dry matter in the leaves of an Elberta peach tree eight years old. Probably in a mature peach orchard nearly a ton of dry matter is added to the soil annually by the leaves. If there is any growth of cover-crop or weeds in the orchard, all of these leaves will be held and ploughed into the soil.

If, in addition to this large amount of organic matter supplied by the leaves, the cover-crop should be a heavy one and one high in carbon in relation to nitrogen, that is, one that would become mature and woody before winter, and if the ploughing should be done rather late in spring, it seems possible that sometimes the supply of nitrate nitrogen might be temporarily reduced in early summer, when the tree makes most of its annual growth. In very fertile soils, with kinds like the apple that do not require a very high soil nitrate content, this might not be injurious; but with other kinds growth might be reduced. Remedies suggesting themselves are to plough in the fall or very early in the spring, or, during a few years, to use cover-crops that will be young and succulent when ploughed under or, as a last resort, to apply available nitrogen.

Cover-crops for mild semi-arid climates. In most orchard sections of California the winter temperature is suitable for the growth of some cover-crops, and the water supply is most abundant in winter. It is, therefore, both possible and desirable to grow the cover-crop during the winter months. In some though not in all soils in such semi-arid climates the growth of a cover-crop, in order to keep the soil in good tilth and to keep some mineral nutrients such as calcium and perhaps iron in available form, seems to be of greater importance than in humid sections. This is true particularly in Citrus orchards, where, because of the very large nitrogen requirement and the injuries that follow the use of large quantities of concentrated nitrogenous material, very large amounts of organic material must be incorporated in the soil if maximum production is to be obtained. Vaile (720) seemed to find, in Citrus orchards in southern California, that a good winter leguminous cover-crop was about equal to five tons of manure. However, in a light soil it required about ten tons of manure a year in addition to the cover-crop to keep the organic matter of the soil equal to that of a virgin soil. Trees in soil so treated gave the highest yields.

Because of the great depth to which the tree roots penetrate and to which nitrogen is found in these soils (Loughridge, 659), and because the nitrate-nitrogen supply does not seem to be as low in the spring as with soils in humid sections having rather long cold winters, there does not seem to be much danger that ploughing under a cover-crop in a rather mature state late in the spring will injuriously lower the nitrate-nitrogen content of the soil. But it is usually desirable to plough it under rather early to avoid great loss of water. In orchards where irrigation is not practiced it is desirable to plough under the cover-crop before the end of the rainy season so as to avoid excessive loss of water and to insure that decomposition of the cover-crop will begin before the soil becomes rather dry. In irrigated orchards the cover-crop is ploughed under before the first spring irrigation.

The crop that is probably the most widely used in California is bitter clover (*Melilotus indica*). In tests at Riverside, California, this plant used as a green manure seemed to cause a greater increase in yield of cereal crops following than did vetch, bur clover, or Canada field peas. Since it does not grow well in very cool weather it should be planted about September 15th. This is not generally feasible unless the soil can be irrigated before the planting. In orchards where irrigation water is not available in the fall or where the winters are cooler than in the average section, purple vetch is often used, since it makes better growth during cool weather than does bitter clover. It may be planted as late as November 1st. Kennedy (644) suggests bitter clover, hairy vetch, bur clover, and lupines as winter-growing cover-crops for sandy land; peas, Tangier peas, horse beans, and fenugreek for heavy soils; and hubam clover, hairy vetch, and horse beans as alkali tolerant. Bitter clover grows well in heavy soils, though sometimes a crust formed soon after seeding may prevent the young plants from getting through the surface of the soil. Kennedy (645) stresses the small seeded horse bean as a promising coarsely vegetative crop that grows more satisfactorily during cool winters than does bitter clover.

Vaile (720) thinks there is some evidence that better growth results if cover-crops are rotated, different legumes being used in different years. He seemed to find that in California summer cover-crops have been injurious whenever used in Citrus orchards. A few deciduous fruit orchards have been very productive under a summer cover-crop system or without any cultivation; but the supply of irrigation water was abundant and rather inexpensive. Generally, in such orchards less pruning is necessary because of the abundant water supply; and, apparently, there is a smaller supply of nitrate nitrogen than in cultivated soils; but enough for medium vegetative growth and good size of the fruit. With pears such treatment seems to cause the trees to have greater resistance to blight than have trees more heavily pruned and with the larger nitrate supply of cultivated orchards. However, in most orchards the water supply is not sufficient for such a practice; and probably in many the supply of available nitrogen might be too low if the soil were never cultivated during part of the growing season.

Time of ploughing the orchard. In most orchards the first working of the soil each year is with the plough, though in many it is with the disk or with some other light cultivating tool. We need more evidence concerning the most desirable time for this initial working of the soil, though what meager information we have suggests that, in some sections with some kinds and varieties, it should be as early as possible. Lyon and Bizzell (662 and unpublished) seemed to find that nitrates begin to accumulate more rapidly after the soil has been stirred. In some preliminary studies they find that, in the climate of New York, by May 8th and by July 15th more nitrates are present in soil ploughed in the fall (November 11th) than in soil ploughed in the spring (May 9th). From this it would seem that the earlier the soil is stirred the better the supply of available nitrogen will be in early summer, when the tree is making most of its new shoot and leaf growth and is setting fruit. The effect of delaying this ploughing until growth has started is to be observed in some orchards in the small growth and the pale color of the foliage. Certainly any one who will observe many orchards, in New York, will be convinced that the vigor of the tree is rather strikingly reduced by delaying the spring ploughing. Experiments are needed to determine as accurately as possible how expensive such delay may be and whether or not it is equally harmful with all fruits. It seems possible that the harm might be greater with the apple, which seems not to resume growth readily, after it has been checked, than with the peach, which upon return of favorable conditions resumes growth readily after having been checked in early summer. It would probably be more harmful with mature trees, that are checked easily, than with young trees.

We have seen, in Chapter 10, that if the nitrogen supply in the tissue is very low at blooming time nearly all of the flowers may fall without setting fruit. If, because of delay in the spring cultivation, the nitrate-nitrogen supply is very small and if the supply during the previous summer was not large enough to cause the storage of considerable amounts of nitrogen in the tissues, too large a percentage of the blossoms, of some varieties at least, may fail to set fruit. On the other hand, with some varieties that set very heavy crops and tend to bear in alternate years, it is possible that delaying the spring ploughing and thus reducing the nitrate supply might, by causing the setting of only a medium crop, tend to bring about annual bearing. Danger, however, lies not only in the possibility that too much of the bloom may fall and too small a crop be left, but also in the possibility that the nitrogen supply might remain low so late that the buds would go into a resting stage before the initiation of fruit-bud formation. However, we have seen that a low nitrogen supply seems to be more detrimental to the setting of fruit from the flowers than to the formation of fruit buds. Even if delaying the spring ploughing should ever tend to promote annual bearing such a practice could be desirable only with trees at an age when rather large annual increase in size is not of great importance. With young trees that do not occupy nearly all available space in the orchard, delaying the spring ploughing would probably cause greater loss through reduction in growth than could be compensated for by any increased tendency toward annual bearing. In light sandy or gravelly soils low in available nitrogen such a practice would almost certainly cause too great reduction in both growth and fruitfulness of old as well as young trees and would probably not reduce the tendency toward alternate bearing. On the other hand, with mature trees in a rich retentive soil in a climate favorable for the setting of heavy crops, there would seem to be the possibility that doing the spring ploughing as late as the time of full bloom or later would tend to prevent the setting of excessively heavy crops and thus, with some varieties, to make possible the setting of fruit buds for the succeeding year.

We have seen that Lyon and Bizzell found more nitrates in the soil in early summer if it had been ploughed in late fall. If the cover-crop is not one that lives through the winter, it may be incorporated in the soil in a more succulent condition if ploughing is done in the fall. Besides these benefits from fall ploughing, there is the fact that in the spring the pressure of other work or the condition of the soil often causes the spring ploughing to be delayed until it is too late for best results. And, if no harm could result from it, fall ploughing would certainly be a commendable practice. There is one danger involved. When the cover-crop is ploughed under in the fall, the wind will come in direct contact with the soil, removing heat much more rapidly. The soil is thus more liable to reach a temperature low enough to kill the roots. This danger exists, however, only in sections at high latitudes where the soil freezes very deeply, or in very sandy or gravelly soils that freeze to considerable depths very quickly. The experiment station orchard at Cornell University at Ithaca, New York (latitude 42.27°), has been ploughed in the fall for ten years; and, although there have been two very cold winters, no root killing has resulted. This soil varies from a heavy clay loam to a rather compact sandy loam. Probably more than three fourths of the orchards in New York State south of latitude 43.3 are so located that there would be less danger from root freezing than there is in this orchard. However, in orchards at higher latitudes or in very light open sandy or gravelly soils, unless the temperature is markedly influenced by bodies of water, root freezing under bare soils is rather common; and the soil in such latitudes should be covered by some vegetation to protect it against contact with the cold winds.

Time of ceasing cultivation. While it is well established that annual cultivation is necessary unless the same purpose is served by a mulch or by heavy spring applications of nitrogen, it does not necessarily follow that cultivation, let us say until August, will give better results than cultivation only until June. In humid sections with fairly cold winters, tillage is as important for its effect on the nitrate supply as for its effect on the water supply; and it is the spring ploughing that most largely influences the nitrate supply. If cultivation continues late into the summer generally neither the weed growth nor the cover-crop will be large enough to maintain a good supply of vegetable matter in the soil; and we can say with certainty from observation in orchards, even where the water supply is not adequate, that it is the spring or fall ploughing that has the marked influence upon the behavior of the trees. In the Ozark region of the United States where, in almost every year, trees suffer from inadequate water supply during a part of the summer, I have observed peach trees that were not ploughed growing by the side of trees that were ploughed in spring only, and these near trees that were ploughed in the spring and cultivated several times during the season. Trees not ploughed at all made but a small percentage of the growth made by trees of the same age that were ploughed in spring. Yet if there was any difference between the growth of these last and that of trees that had more cultivation the difference was so small that it could be measured only by careful experimentation.

There is need for careful experimental study of this problem. If it should be found that in many sections cultivation may well cease when the soil has been ploughed and worked down in the spring, the use of a leguminous cover-crop in latitudes too high for the growth of cowpeas might be found more desirable. Thus, if clover or vetch could be sown by June 1st, it is probable that the nitrogen supplied in soils where the kind of trees being grown will respond to additional nitrogen would be worth more than the cost of the seed. Such early ceasing of cultivation would of course reduce the cost of soil management, and it might by reducing the nitrate-nitrogen supply in late summer cause a better coloring of some kinds of fruit; for in many sections even a legume, though increasing the total nitrogen supply, will, while growing, tend to cause a reduction in the supply of nitrate nitrogen in the soil. However, it is probable that in some sections in some years ceasing cultivation and sowing a cover-crop or permitting the weeds to grow early may cause such a large loss of water in late summer that the fruit will be reduced in size. Crane (591a) seemed to find such a result in West Virginia.

Effect of cultural methods on soil temperature. The fact has been mentioned that a cover-crop or stubble in the orchard in winter prevents the soil from reaching as low a temperature as it would otherwise reach. It seems possible that by influencing summer soil temperatures also a cultural practice might influence the behavior of some fruit plants. Thus, cool soils are often recommended for some fruits, such as gooseberries and currents. The mulch system maintains the soil at the lowest temperature in summer, and also the highest in winter. Oskamp (679), however, found with apples that, while the widest variations in temperature were between the mulched plats and those under cultivation with cover-crop, these plats were most nearly together as to growth of trees. Thus difference in temperature was a matter of minor importance, if of any importance at all, in determining the growth of apple trees. As to whether or not the lower summer temperature maintained by the mulch would be of benefit to crops like gooseberries, that are said to prefer a cool soil, we have little or no evidence.

Soil Nutrients

The use of nitrogen in orchard management. It seems well to discuss separately the use of nitrogen, since the supply of available nitrogen is so strikingly influenced by methods of soil management and since nitrogen has been shown to be of such great importance as influencing growth, the formation of fruit buds, and the setting of fruit. A lack of available nitrogen sufficient for healthy growth can be readily observed by the appearance of the trees of most kinds of fruits. In summer the foliage of trees having an insufficient nitrogen supply is of a pale green or yellowish green color as contrasted with the deep green of trees having an abundant nitrogen supply. The difference is more striking with some kinds, such as the peach, than with others, such as the apple. A yellowish color in the foliage is occasionally observed that is due to other causes than lack of nitrogen, as, for example, a soil condition that renders iron unavailable. However, such injuries are generally more striking and more liable to prove fatal, and are generally easily distinguishable from the yellowish color due to lack of nitrogen. In winter the bark of trees grown with insufficient nitrogen tends to have a bright reddish color as contrasted with the dull dark color of the bark of trees grown with an adequate supply of nitrogen. It may be that this color is due to an excess of carbohydrates resulting from the low nitrogen supply. A similar color of bark in winter, as well as a yellowing of the leaves, is eventually to be observed on branches or trees that have been ringed unless the ringing wound heals over. We have seen in Chapter 1, that Curtis (95) found ringing greatly to reduce the amount of nitrogen in the tissue above the ring, and that he thinks nitrogen tends to move mainly through the phloem.

Kinds of nitrogenous fertilizers. Nitrogen may be used in forms in which it is immediately available to the plant or in forms in which it is very slowly available. Of the forms commonly used, sodium nitrate is most quickly available. Ammonium sulphate and dried blood become available rapidly enough to cause growth response rather quickly; though, in all soils, there will, in the following spring, still be nitrogen becoming available from applications of these substances, while in many soils no effect of sodium nitrate can be observed one year after the spring of application. In some grades of meat and fish scraps also the nitrogen is rather quickly available. Manure must be used in rather large quantities if it is to furnish enough quickly available nitrogen in the spring in an orchard that is badly in need of nitrogen applications. The nitrogen in bone meal and tankage is in perhaps even less available form.

Some plants show better response to organic than to inorganic forms of nitrogen. Such responses of the different fruits will be studied in the next chapter. In principle, readily available forms would seem to be the more desirable, since with them one can be certain of having the nitrogen at the season when it is most needed; and there are conditions, as with apple or pear orchards in sod, with which application of readily available nitrogen in the spring certainly is necessary. Sodium nitrate would then be desirable though ammonium sulphate or dried blood might give nearly as satisfactory results, if more nitrogen were used. In a cultivated orchard it would be possible by use of slowly available forms to bring the soil to such a condition that the supply of available nitrogen would be adequate; but during the first few years in which the orchard was fertilized it might be desirable to mix with the slowly available form some that is quickly available.

Both sodium nitrate and ammonium sulphate when used in rather large quantities, particularly if the soil is an open sandy or gravelly one, may kill the leaves and even the trees. However, most other plants are more easily killed than are fruit trees by excessive applications of these substances. With fruit trees, only excessive applications can be injurious. With strawberries and some other small fruits the danger is greater and these substances must be spread lightly. With the organic forms of nitrogen this danger is not involved. Further, particles of sodium nitrate and ammonium sulphate will kill any foliage on which they lodge; while no form of organic nitrogen with which I am acquainted causes such injury. In sections where irrigation is necessary the continued use of sodium nitrate often proves injurious to the trees. Vaile (719) found that sodium nitrate may, after six or seven years of continuous usage, cause serious development of mottle leaf in citrus trees grown under irrigation where the winter rainfall is light. In such sections this trouble may develop, but generally to a less extent in orchards in which sodium nitrate is not used. Coarse organic forms such as stable manure gave the best results both as to yield and as to overcoming mottle leaf. Dried blood, though better than sodium nitrate, did not prevent the development of a considerable amount of mottle leaf. Neither did ammonium sulphate, though the work with this substance was not extensive enough to give conclusive information. Gardner *et al.* (604) in Pennsylvania found that ammonium sulphate increases the acidity of soils in humid sections enough to be injurious to clover. Serious acidity following long continued use of this substance has been observed by several workers in England (Hall, 617); but the condition was easily corrected by applying lime; and it can be avoided by using sodium nitrate for about half the nitrogen requirement, its alkaline residue partly or completely offsetting the acid effect of ammonium sulphate application. Long usage of large quantities of sodium nitrate has been observed by many workers to cause a bad physical condition in clayey soils; to defloculate some of the clay. This probably would never be serious in orchard practice except with citrus trees having a very large nitrogen requirement and in soils in arid regions where there is little leaching and where there is often a considerable amount of saline matter in addition to the sodium of the fertilizer.

Time of applying nitrogen. It has been shown, in Chapter 10, that, with apples, where the supply of nitrate nitrogen is very low in the soil, the percentage of flowers to set fruit can be increased if available nitrogen is applied to the soil two or three weeks before the bloom. Such an early application of nitrogen would certainly be desirable under conditions such that a very large percentage of the flowers would otherwise fall without setting fruit. However, there will probably be degrees of nitrogen deficiency such that a fair crop may be set without fertilization. It is possible that under such conditions delaying the application of nitrogen until blooming time or a little later might by permitting the dropping of a large percentage of the flowers and the setting of only a medium crop tend to encourage annual bearing. However, it is not at all certain that such a result would follow.

The light setting would certainly be favorable to annual bearing, but there is not conclusive evidence as to what effect late spring applications of nitrogen would have on fruit-bud formation. I have known June application of nitrogen to peach trees in the gravelly soils of the Ozark region in Missouri greatly to increase the formation of fruit buds in the same year. In that section peach trees bloom about April 1st. However, apple and pear trees do not tend to continue growth nearly as late as peach trees grow; and the fruit buds are generally on spurs or twigs that cease growth within a few weeks after the bloom. It is possible that such buds would be too far into the resting stage for nitrogen applied in June to cause fruit-bud formation. With mature trees of kinds such as the apple and the pear most of the growth even of vigorous trees is made within a few weeks after spring activity begins; and so if the nitrogen is applied later than blooming time it will probably not get to the growing points in time greatly to influence the growth of even the shoots; the influence on the growth of the spurs certainly would be very slight, thus not bringing about the increased vegetative vigor with which increased setting of fruit buds on weak trees is generally associated.

However, it is possible — though not certain — that the determining factor toward fruit-bud formation in the invigorated spur is the larger amount of nitrogen in relation to carbohydrates. Such a relationship might be brought about through application of nitrogen as late as blooming time or even much later (Hooker, 633) merely by the movement of the nitrogen into the spurs even though this supply of nitrogen came too late to influence the growth of the spurs. Thus there seems to be the possibility that, with apple trees whose nitrogen supply is not so deficient as to cause nearly all of the bloom to fail to set fruit, delaying the application of nitrogen until it is too late to stimulate increased setting might be a means of avoiding the influence toward alternate bearing caused by the setting of excessively heavy crops that must be thinned; and that the nitrogen might yet reach the spurs and twigs in time to cause the formation of fruit buds.

It should be emphasized, however, that only when the nitrogen supply in the soil and in the tissue is low in spring could such a result be expected. The most striking example of this condition is to be found in sod orchards or orchards in soil exceptionally low in available nitrogen where nitrogen has not been applied during the previous year. If the application of nitrogen is very large, even though of a readily available form, and the soil is of a retentive nature and is cultivated, it is probable that by the next spring there will be some of this nitrogen in the soil; perhaps enough to cause heavy setting and thus to cause alternating. On the other hand, if the soil is of a light sandy or gravelly nature, or if the orchard is in sod, particularly if no more than about three hundred pounds of sodium nitrate is applied — in the climate of Missouri at least — nitrogen applied in one spring does not seem appreciably to influence the growth of the trees in the next.

Roberts (701) has found that apple trees in pots growing with an abundant nitrogen supply store large quantities of reserve nitrogen. Trees grown with a high nitrogen supply in 1920, but transferred in the spring of 1921 to a medium with no nitrogen, except the small quantity in the tap water, made nearly as much growth in 1921 as trees made that were left with an abundant nitrogen supply. However, the nitrogen in the tissue of the former was reduced during 1921 from .99 per cent to .32 per cent, while in the latter it was reduced only from .99 per cent to .90 per cent. Yet Hooker (632) seemed to find that early spring application of nitrogen to trees in the orchard does not increase the nitrogen content of the spurs in the following spring. The application of Roberts's results to field conditions would probably be limited in two ways. First, these trees apparently had an abundant nitrogen supply throughout the summer of 1920; while, in sod orchards or orchards growing in light sandy or gravelly soil unless the applications are very large, the nitrogen supply might be very low before the end of the summer. Thus, Lyon, Heinicke, and Wilson (664) found, in a sod orchard to which 300 pounds of sodium nitrate was applied to the acre, that nitrate nitrogen was reduced from 40.67 pounds to the acre on April 25th to 3.33 pounds to the acre on July 12th. It is not probable that under such conditions there would have been much storage of nitrogen. Second, these young trees apparently were not blooming in the spring of 1921. The amount of nitrogen removed by the bloom must be very large. Howlett (191) found that about five per cent of the dry weight of young apple flowers is nitrogen. If there had been this drain on the reserve nitrogen and the soil nitrogen supply had been low after early summer it is doubtful if that reserve would have been large enough to cause so much growth.

The above discussion concerns early spring as compared with late spring application. Hooker (633) has raised the question as to whether or not fall applications may be desirable. He seemed to find that, while early spring applications of nitrogen would not increase the nitrogen content of the apple tree bark and spurs of the following spring, summer and fall applications would do so rather markedly. He does not give any data indicating the amount of nitrogen that can be got into the spurs by blooming time if the nitrogen is applied about three weeks before the bloom. We know, however, that enough can be got in to cause a good percentage of the flowers to set fruit even with orchards in soils with a very inadequate supply of available nitrogen. Any benefit of fall application over applications in early spring must, therefore, be due to an influence on growth or fruit-bud formation rather than on fruit setting. He seemed to find that, while spring application of nitrogen tends to reduce the starch content of the spurs by the following July, application during the previous summer increases it. This suggests that fall application of nitrogen might tend to cause the development of a condition favorable for fruit-bud formation. It would require more determinations with many different trees to give conclusive evidence that fall application of nitrogen causes the accumulation of more starch in the spurs during June. And since the evidence as to the relation of the accumulation of starch to fruit-bud formation is not very conclusive the data can be only suggestive until the actual effect on fruiting of fall applications of nitrogen has been studied.

Hodsoll (630) applied somewhat unavailable organic manures like meat meal or meat and bone meal in winter and a more soluble organic fertilizer in August and obtained four successive good crops with varieties that tend to bear alternate crops. However, he does not report the use of any checks and he did not compare this treatment with as heavy applications given at one time in the spring. It may be that the annual crops resulted from the fact that much nitrogen was used rather than from the fact that some of it was applied in late summer. Or the annual crops may have been the result of some other orchard practice such as heavy pruning. This discussion applies primarily to apples and pears. With other fruits we have less evidence that spring application of nitrogen would increase the percentage of flowers setting fruit. Crane (591a) found early spring application of nitrogen to peach trees in West Virginia even less valuable than applying at blooming or later.

Hodsoll's trees were in the climate of England where danger of winter freezing is very small. It is interesting to note that Hooker apparently found in Missouri no winter injury to follow autumn application of nitrogen. The nitrogen was of course applied too late to cause a resumption of growth, but it does not seem impossible that the absorption of large quantities of nitrogen late in the season might cause chemical changes in the tissue that would reduce resistance to freezing; though there is no experimental evidence that it would. Heinicke applied nitrogen late in the season to a number of apple trees at Ithaca, New York, and there was no injury during the next winter; though some of these trees were of the very tender variety, Baldwin. It is certain, then, that fall application of nitrogen does not greatly change the resistance of apple trees to low temperature. There remains the slight possibility that it would reduce resistance enough to be of importance in very cold winters.

With young trees, generally rapid growth is desirable in order to develop a large bearing surface as soon as possible; and with such trees early spring or late fall applications of nitrogen seem most desirable in any soil with which applications of that element are necessary for the maximum growth of fruit trees. Under some soil and climatic conditions there must be a large loss of nitrogen through leaching when it is applied in the fall; and, under such conditions, spring application would probably be most desirable. In fact, until we have further evidence, it seems probable that the wisest plan would be to practice early spring application with young trees and with bearing trees, if readily available nitrogen is used; for we have had more experience with applications at that time. When such slowly available substances as stable manure, tankage, or bone meal are used, probably any time from late summer to early spring would be satisfactory. Any reduced benefit resulting from applications later than two or three weeks before the bloom may be greater with some kinds than with other. Such differences in response will be considered in the next chapter.

The method of applying nitrogen. The method of applying nitrogen, that is, whether it is spread in as wide an area as that of the tree roots or in a smaller area, may be of some importance. That it should be spread evenly in an area surrounding the tree is certain; for Auchter (30), Knowlton (649), and others have shown that of the nitrogen taken up by certain roots, all, or nearly all, goes to specific branches; there is not much crossing over; and if all of the branches are to receive nitrogen it must be so spread that all of the main roots will receive it. It is certain from practical experience that, with soils in which trees respond to applications of nitrogen, spreading it over an area no wider than the spread of the branches, which is generally considered less than the spread of the roots, will give very satisfactory results, at least temporarily. Gile and Carrero (608) found that, with corn grown in a nutrient solution, the assimilation of an element is reduced when not all of the roots are in a medium containing that element. However, dividing the roots and placing some in a solution without an element is different from distributing fertilizer evenly around a tree, but on a circular area of soil smaller than the spread of the roots. In this latter case all of the main roots will receive the element through lateral branches. It seems probable that if the supply of nitrogen in this area of soil is abundant it may be supplied to the tree as fast as it can be transported to the growing point and used.

In a sod orchard, it is possible that nitrogen might be saved by spreading it in such a reduced area; for not so much would be used for growth of the grass; the grass outside the fertilized area not being stimulated to additional growth. Further, if sodium nitrate or ammonium sulphate were used in considerable quantities the concentration on this reduced area might be great enough to kill the grass; and a larger percentage of the nitrogen might remain in an available form. Ballou (561) found five pounds of sodium nitrate spread on a mulched area, that was about equal to the spread of the branches, to give as good results as ten pounds of sodium nitrate to the tree spread over all of the ground between the trees, no mulch being used. However, this experience does not answer the question here discussed; for there are too many uncertain features. The mulch by keeping down the grass would increase the supply of nitrate nitrogen; but we do not know how much; and it is not certain that a tree requires ten pounds of sodium nitrate for maximum growth and fruitfulness.

It would seem that, in soils very low in available nitrogen, spreading nitrogen over an area smaller than the spread of the roots might influence the nature of the root system. Knight (470) planted parsnips in a layer of soil low in nutrients; the layer being eighteen inches deep. Under this was a layer of soil with much fresh vegetable matter incorporated. After a season's growth the roots were examined and were found to have gone through the poor soil with little branching, but to have formed a thick network of branches in the rich mould beneath. In an adjacent plat the rich mould was placed on the surface with the soil low in nutrients underneath. In this there was much branching of the roots in the surface layer, but few penetrated the infertile soil though the parsnips made a good growth. Nobbe (492) obtained similar results with clover. Weaver, Jean, and Crist (535) found that where roots of corn, barley, oats, and potatoes came in contact with layers of soil which had been fertilized with sodium nitrate, they grew more rapidly and branched much more profusely; and such a fertilized layer retarded the penetration of the roots into layers of unfertilized soil. Knight (470) describes an experience of Du Hamel with a tree planted at the intersection of two trenches. When the tree was dug some years later the roots were confined almost entirely to the soil where the trenches had been. He thinks the trenches must have been filled with surface soil containing perhaps an abundance of nutrients. It seems possible then that, with trees in soil low in nitrogen, if nitrogen bearing fertilizer were spread only as wide as the spread of the branches, the roots might tend to remain in that area to a greater extent than they would if the nitrogen were spread over the entire area. This might tend to reduce the water supply by reducing the area of soil drawn upon by the tree. We know only that no such injurious effect has been so striking that it has been observed in experience; even in sod orchards where, in unfertilized soil, the nitrate nitrogen supply is very low. And it seems probable that there is enough nitrate nitrogen even under sod for root growth to proceed rapidly enough effectively to occupy all the soil between the trees. But the problem has not been studied carefully; and in few orchards has the application of nitrogen been practiced long enough for any possible injurious effect of spreading it around the tree in an area much smaller than the spread of the roots to become striking.

We have seen, in Chapters 1 and 4, that the use of nitrogen under conditions such that the trees will show marked response will increase the growth of the top more than it increases the growth of the roots. It was suggested that the use of nitrogen might thus reduce the water-supplying power of the roots as compared with the transpiring power of the leaves. However, it should be emphasized that root growth is increased by use of the nitrogen, though less than is top growth; and a larger percentage of the weight of the roots is young absorbing surface. Further, the greater branching of the roots in soil with a good nitrogen supply should increase the absorbing power both by increasing their absorbing surface and by increasing the percentage of the soil with which roots are in contact. We have seen, in Chapter 8, however, that in actual experience sometimes the fruit on trees, that have made rapid growth response to application of nitrogen, showed greater water deficits during clear days in dry times than fruit on unfertilized trees showed. This problem will be discussed further as to the responses of the different kinds of fruit trees in the next chapter.

Determining amounts of nitrogen to apply. The amount of nitrogen to use cannot, of course, be determined in any general way but must be determined by conditions in the orchard, such as the nature of the soil and the presence or absence of sod. Trees of most kinds, if not of all kinds, will make good response to applications of nitrogen in almost any soil if the orchard is in sod. On the other hand, the soil must be relatively low in nitrate nitrogen before trees of some kinds, such as the apple, will respond to applications of nitrogen in a cultivated orchard. Probably the earliness of the spring ploughing will influence the amount of nitrogen to which trees will make profitable response. If ploughing of the orchard was delayed until after blooming time, application of nitrogen might be profitable in apple and pear orchards with which, if cultivation began earlier, the supply of nitrate nitrogen in the soil would be adequate. Of course, under such conditions the better plan would generally be to do the spring ploughing earlier rather than to apply nitrogen.

The relation of the water supply to the response of trees to applications of nitrogen should be studied. It is probable that with an abundant water supply trees would respond in growth and, probably, also in yield, to larger quantities of available nitrogen than that which would be adequate if growth and yield were strikingly limited by lack of water in summer.

With trees that make additional response to increasing quantities of nitrogen up to very large amounts, the price of the crop is important in determining how much it is profitable to use. The price of fruit is generally high enough to justify, for the sake of small additional yields a greater expenditure than would be profitable with most other crops. Then, with trees that have not yet reached maximum bearing, additional growth makes possible additional yield, not alone in the year of the application, but in succeeding years also.

With fruits like the apple, the peach, and some plums, that require direct sunlight to develop the best color, the amount of nitrogen that it is wise to use may be limited also by its influence on color. When the use of nitrogen causes very rank vegetable growth with large leaves the amount of shade in the tree is greatly increased and the amount of red color thus reduced. The use of nitrogen tends to delay the maturity of fruit and wood, and, with fruits that ripen late in the season, may in that way also reduce the color of the fruit. With varieties that ripen long enough before freezing weather, reduction in color due to late maturity is, of course, avoided by delaying the picking.

The response to applications of nitrogen is different with different kinds of fruit. Thus, the peach tree will respond in growth and yield to applications of nitrogen in soils in which the apple tree will show no response. It is only by studying the responses of some kinds of fruit as compared with that of other kinds, and with that of field crops that we may hope to obtain information that will be helpful under various soil and cultural conditions. A review of evidence in search of such information will be given in the next chapter.

The use of other elements than nitrogen. It is the purpose here to discuss not all of the elements that are essential for plant growth, but only those which sometimes are not present in sufficient quantities for the best development of the plants or which are sometimes present in harmful quantities.

Sodium (*alkali*). Sodium is not an essential element for plants, but some of its compounds often greatly influence the behavior of crops, being the chief harmful substances in alkali soils; sodium carbonate giving what is known as black alkali. In such soils generally potassium and other bases may be found in rather large quantities. Alkali soils are found in sections with too little rainfall to leach out the salts formed by the weathering of the rocks; and in such arid or semi-arid regions even soils not injuriously alkaline are generally rather high in water soluble mineral constituents. Soils in which the trees make good growth may, after a considerable number of years of irrigation practice, come to be alkali soils. This may result from sodium compounds in the irrigation water or from the rising of the water table and the bringing up of substances from lower strata. Unless drainage is particularly good there is much danger that alkali will be brought into the lower areas of an irrigated orchard by the rising of the water table and by the leaching in of alkali from higher areas.

A soil that does not have a high content of water soluble sodium compounds may still be an alkali soil, very toxic to plants and very difficult to reclaim if there is relatively a large amount of sodium among the replaceable bases. Kelley and his associates (593, 640, 641) and others find that, in the clay fraction of the soil, ions of calcium, magnesium, potassium, and sodium are held in some way in which, though not soluble in water, any one may be quickly brought into solution by exchanging places with another in a soluble combination; the replacement activity of the calcium ion being highest, followed in order by that of the magnesium, the potassium, and the sodium ion, that of NH_4 being about equal to that of the potassium ion. Thus, the calcium, the magnesium, or the potassium ion in a soluble compound may replace the sodium in this replaceable form, the sodium entering into the soluble form; and so, if there is much replaceable sodium in the soil, it is likely to be brought into solution in sufficient quantities to be highly injurious to plants. Therefore, in considering the possibility of correcting an alkali soil, the replaceable as well as the soluble sodium must be reckoned with. When calcium is largely the predominant base among these compounds the soil does not generally have an alkaline reaction, tends to be friable due to floculation, and generally is a medium favorable for plant growth. On the other hand, when sodium or potassium is present in excessive proportions as a replaceable base, the soil tends to be tenacious in texture and toxic to plants.

Kelley and Thomas (643) and Cummins and Kelley (593) have studied the development of a mildly alkali soil through the application annually for fifteen years of large quantities of sodium nitrate (nine hundred pounds to the acre to mature trees), the calcium carbonate content of the soil being low at the beginning. During the first few years the treatment caused the orange trees to make a vigorous healthy growth but later they were seriously injured, the soil having become tenacious and apparently low in available calcium. Hall (617) describes experiences in which the application of large quantities of sodium nitrate caused the formation of considerable quantities of sodium carbonate and the development of an alkaline reaction in a soil in the humid climate of England; also the development of greater tenacity in the soil. He reviews work of others showing that the plant does not take up nearly as much of the sodium as of the nitrate ion and that sodium accumulates in the soil. In humid regions the sodium is leached out to such an extent that the soil does not become seriously toxic to plants.

In arid regions there seems to be much less danger from such injury if the soil is rich in calcium both in the replaceable form and as calcium carbonate, the injury developing most rapidly in light sandy soils low in calcium and rather high in other bases. Serious injury from the use of sodium nitrate has not yet been observed in parts of California where the winter rainfall is sufficient to cause a considerable amount of leaching and the soil is rather heavy.

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Calcium. While this is an essential element used in large quantities by plants, in humid sections, it is generally present in large enough quantities for the direct needs of plants. In arid sections, when sodium or potassium in the soil solution or in the insoluble compounds discussed by Cummins and Kelley are present in very large proportion, there may develop conditions under which there does not seem to be an adequate supply of available calcium. Reed and Haas (690–92) found that orange trees and walnut seedlings are more sensitive to lack of calcium than to lack of potassium in the culture medium. Orange trees grown in a medium lacking calcium developed an appearance much like that of mottle leaf found in the field.

In humid sections the use of lime in soil management is mainly to correct acidity and nearly all if not all deciduous fruits are so tolerant of soil acidity that in such regions using lime will rather seldom be necessary unless it be used for its effect on the cover-crop, or possibly in extreme cases for its floculating effect on the soil.

Iron. While this is an important essential element for plants, it is usually present in the soil in quantities large enough for their needs. However, in soils excessively high in calcium or other substances that may cause an alkaline reaction the iron may be in an unavailable form, or it may become unavailable after entering the plant; and under such conditions the trees may develop chlorosis, the leaves becoming yellowish green or yellow and the trees eventually dying. Thus pineapple plants show chlorosis in calcareous soils in Porto Rico (Gile, 606). Some preliminary studies with chlorotic pear trees by Mr. Yousif Milad at the University of California suggest that in highly calcareous soils the iron may be taken into the tree in about as large quantities as with trees in normal soils; but the trees become chlorotic and can be rehabilitated by application of iron in certain ways. Johnson (636) found in Hawaii that a high concentration of manganese, even in a soil with an acid reaction and no calcium-carbonate present, causes, in pineapple plants, serious chlorosis which is corrected by treatment with iron.

Some fruit plants are much more tolerant of this condition than are others. Revière and Bailhache (696) say, that in parts of France, chlorosis is very common with pear and quince stock in calcareous soils. These workers (697) were able to cause chlorotic branches to develop normal leaf color by supplying a weak solution of pyrophosphate of iron through a glass tube inserted through a cork in a hole bored in the branch. Putting plugs of iron sulphate into holes bored in the trunks of trees is thought to cure chlorosis; but Rivière and Bailhache (697) did not find this method satisfactory; the green color not being restored evenly in all of the branches. Professor Hendrickson seems to find the application of rather large quantities of iron sulphate around the roots of pear trees (the soil being first dug away to the large roots) in calcareous soil rather effective as a means of restoring the green color after the leaves have become seriously chlorotic. However, with pineapples spreading ferrous sulphate evenly in the soil has not been very effective. Johnson and Ching (637) say that application of iron sulphate to the soil at the rate of five hundred to three thousand pounds to the acre did not prevent chlorosis. Probably the method used by Hendrickson was more effective because the ferrous sulphate instead of being spread over the soil was placed around the large roots of the trees in such large quantities that, in the small area in which it was located, there did not soon come in contact with it enough of the soil solution to render it insoluble or to cause it to be in a form easily precipitated in the plant. Gile (606) found that, while treating the soil of potted pineapple plants with a solution of ferrous sulphate did not cause the leaves to regain their green color, putting crystals of the ferrous sulphate in the soil caused the plants to become green and to make a healthy growth. It is possible that with slightly alkaline soils chlorosis could be prevented by the use of very large quantities of organic manures, the organic matter tending to render the soil acid or, at least, neutral and also to supply iron in an organic combination in which form it might remain soluble long enough to supply the small quantities needed by the plants, though it is probable that impracticably large quantities of such organic matter would be required. Sorauer (706) quotes Gris as reporting in 1875 that chlorotic leaves will become green if painted with a soluble iron salt. Gile (606) found that pineapples will recover from chlorosis if the leaves are treated with ferrous sulphate, a two-per-cent solution being put on with a brush. Even dropping a crystal into the center of the leaf whorl of seriously chlorotic plants, though it killed the center leaves, caused the others to become green and a healthy new sprout to start. Gile did not think treatment with ferrous sulphate a profitable means of adapting pineapple growing to highly calcareous soils. However, Johnson (636) seemed to find spraying the plants three times with a ferrous sulphate solution at a strength of ten pounds to fifty gallons of water a very effective means of adapting pineapple growing to soils containing an excess of manganese. Johnson and Ching say that fifty pounds of ferrous sulphate to the acre applied to the plants as a spray was effective in curing chlorosis, though three thousand pounds had not been effective when applied to the soil. Korstian *et al.* (651) were able to correct chlorosis in yellow pine seedlings by spraying at ten-day intervals with a one-per-cent solution of ferrous sulphate. A two-per-cent solution eventually proved injurious. More detailed study with the different fruit plants that may show chlorosis is needed. While the most promising means of correcting the injury seems to be to spray with a one-per-cent ferrous sulphate solution, such a treatment does not seem to be effective with pear trees or red raspberry plants in a calcareous soil in California. The leaves sprayed will become green, but not enough soluble iron will be got into the plants to cause the new leaves to be green. Of course, by chlorosis as discussed here is meant only the yellowing caused by lack of iron. Yellowing from other causes could not be corrected by treating with iron.

Sulphur. This, another essential element, is deficient in some soils, but there is little or no evidence as to the response of fruit plants to such deficiency. Chauzit (584) found applications of sulphur beneficial to grapes in a section of France; particularly when accompanied by large quantities of organic matter. Application of sulphur to some soils, particularly in Pacific Coast sections, is found to be beneficial to alfalfa and to some other leguminous plants that may be used as cover-crops.

Potassium. In humid regions, if not also in some arid regions, the soil potassium supply is often deficient, at least for some crops; not all crops responding alike to its application. There has been a general opinion that a very large soil potassium supply is of exceptional importance with fruit crops. This opinion seems to have prevailed largely as a result of chemical analyses. It was early thought that by analysis of the soil and its crops it should be possible to determine fertilizer needs. Thus, Du Hamel (596) says, "Several learned men, for example, have attempted to analyse the soils in order to learn their fertility: unfortunately the results of their work have never tallied with experience." After it was learned that analyses of the soil give very little information as to its fertility, it was still thought that analyses of the plant tissues might give information as to the probable needs of the plant. It was naturally assumed that the elements removed in largest quantity in proportion to the amounts removed by field crops would be those especially needed for fruit production. Thus, Roberts (699) published, from the results of such analyses, estimates of the amount of mineral nutrients removed by the leaves and fruits of an apple orchard 13 to 35 years old. He assumed the trees to be thirty-five feet apart each way, and that each tree would bear fifteen bushels of apples during each year of the period. The following table gives his estimate as to the amount of nutrients that would be removed from an acre during such a twenty-year period; and also his estimate as to the amount that would be removed by a wheat crop during the twenty years.

TABLE 24. ESTIMATED AMOUNTS OF SOME MINERAL NUTRIENTS USED FROM AN ACRE BY APPLE TREES AND BY WHEAT DURING TWENTY YEARS

	APPLE		WHEAT	
	Fruit (lbs.)	Leaves (lbs.)	Grain (lbs.)	Straw (lbs.)
Nitrogen	498.60	456.75	424.80	234.78
Phosphoric acid	38.25	126.00	160.20	50.40
Potash	728.55	441.00	109.80	214.20

It will be seen from this table that as much nitrogen, three times as much phosphorus, and more than half as much potassium are removed by the leaves as by the fruit. Of course, practically all of that in the leaves, except some of the nitrogen, would be returned to the soil. Considering the fruit alone, however, more than two thirds as much nitrogen would be removed by the apples as by the wheat, though the apples removed much the smaller quantity of phosphorus. Most striking is the amount of potassium removed by the fruit. Of course it should be emphasized that Roberts has assumed what is probably a much larger yield of fruit than would be realized. Van Slyke, Taylor, and Andrews (722) give the results of similar analyses for apple, peach, pear, plum, and quince, except that they also include analysis of the new wood. The following table gives the summary of their results:

TABLE 25. AMOUNTS OF MINERAL NUTRIENTS USED FROM AN ACRE ANNUALLY BY CERTAIN FRUITS

	NUMBER OF TREES AN ACRE	NITROGEN (lbs.)	PHOSPHORIC ACID (P_2O_5) (lbs.)	POTASH (K_2O) (lbs.)
Apple	35	51.5	14.0	55.0
Peach	120	74.5	18.0	72.0
Pear	120	29.5	7.0	33.0
Plum	120	29.5	8.5	38.0
Quince	240	45.5	15.5	57.0

It will be seen, by multiplying the figures in Table 25 by 20, that the various elements are used annually in slightly larger quantities according to this table than according to that of Roberts (Table 24).

Thompson (714) has made extensive analyses of fruit, leaves and twigs of various fruit trees and his results show the same trend shown by those of Van Slyke *et al.* from analyses made in New York. All of these analyses seem to indicate that large quantities of all of the elements, except phosphorus, are removed by fruit trees and that the element used most largely by the fruit is potassium. If the analyses indicate the proportion in which the fruits demand the elements, then we must conclude that fruit has a peculiar need for potassium and that fruit trees may respond to applications of potassium, even in soils where the supply is sufficient for other crops. Probably partly on account of this suggestion from chemical analyses, and partly from the view that potassium improves color, there has developed a rather wide-spread opinion that potassium is the most important fertilizer element for fruit production. While the experimental evidence concerning the responses of each of the important fruits to the different elements will be studied in the next chapter it may be said here that this view of the peculiar importance of potassium in fruit growing has not generally been borne out by experimental studies.

Potassium may be applied in the form of potassium chloride, or potassium sulphate in either of which as purchased in the trade there is approximately fifty per cent of potash (K_2O). It may be applied also in kainit, which contains twelve to twenty per cent of potash, in wood ashes, and in other forms less commonly used. Potassium chloride and kainit are toxic to some plants and particles of either will kill leaves upon which they may lodge. As with sodium nitrate and ammonium sulphate, the toxicity when applied to the soil is less in a clay soil or in one rich in decomposed organic matter than in a very open sandy or gravelly soil. With trees and with strawberry plants potassium chloride seems to be a little more toxic than sodium nitrate used in equal quantities. Alderman (550) reports some results of studies with peach trees in West Virginia in a soil which he does not describe. Potassium chloride used at the rate of one pound around a small tree seemed to check growth slightly; at the rate of two pounds, the toxic effect was very clearly visible, while at the rate of two and one-half pounds the tree was killed. It required five pounds of potassium sulphate around a small tree to kill it. The toxic effect of either form was reduced when used in combination with nitrogen bearing fertilizers. Potassium sulphate does not have the injurious effect upon seeds with which it comes in contact that potassium chloride has and it is probable that its effect on leaves on which particles may lodge is less severe. In sections with very low rainfall, the tendency is for the amounts of potassium salts and of other salts in the soil to be rather large; and, with sandy or gravelly soils low in clay content, the danger of such toxic effects may be greater in semi-arid than in humid sections. It seems that in such dry sections potassium should be used cautiously in the orchard and only when there is practical certainty that it is needed.

Phosphorus. Phosphorus is carried in manure, but in smaller quantities than are nitrogen and potassium. It is used in animal products such as bone meal and tankage, which contain also some slowly available nitrogen, and in mineral forms such as basic slag, raw rock, and acid phosphate. These phosphorus bearing substances when applied to soil even in rather large quantities do not seem to be toxic to the trees, and if spread upon the foliage, even of strawberry plants, are not injurious.

Summary. Tillage conserves the soil water supply by reducing water loss from the surface and by preventing the growth of plants that would transpire water. The latter influence seems to be the more important. By preventing the growth of grass and weeds, and apparently by increasing soil aeration tillage increases the rapidity of the spring and early summer accumulation of nitrate nitrogen in the soil. Sod in the orchard is very injurious to the growth of trees; it may reduce the number of fruit buds formed; and it often causes a very small percentage of the flowers to set fruit. This injurious effect is due to a great reduction in the supply of nitrate nitrogen; the reduction apparently being due to the excretion by the grass of organic matter that is used as food, by soil organisms which use the nitrate nitrogen leaving it in the soil in temporarily unavailable organic forms. Vigorously growing grasses seem to be more injurious to the trees than weakly growing kinds. Even legume sods are slightly injurious to trees in some soils, by reducing the supply of available nitrogen, in spite of nitrogen fixation that increases total nitrogen. The reduction, however, does not seem to be so great but that orchards in alfalfa sod are very fruitful. The injurious effect of grass can be largely, though generally not completely, overcome by use of sodium nitrate in rather large quantities. A mulch of vegetable material thick enough to prevent the growth of grass and weeds is effective in conserving soil moisture, but tends to reduce the supply of nitrate nitrogen as compared with the supply in a soil under cultivation and cover-crop. However, such injury from a mulch is far less than the injury from sod. A cover-crop ploughed under each year improves the tilth and the water holding capacity of the soil. In soils with which application of nitrogen is necessary for the fruit concerned, leguminous cover-crops are desirable for the nitrogen fixed, provided the seed of a kind that can be depended upon to make good growth can be obtained rather cheaply, as with the cowpea or the soy bean, in sections where these will make good growth. While clean cultivation without the use of a cover-crop, during three or four years, generally will not injure the trees, such a practice continued much longer will generally reduce their growth and probably their fruitfulness. In some sections, if a good cover-crop is to be grown, cultivation must cease by July 1st. Ploughing the soil in very early spring or in autumn will insure a better supply of available nitrogen for early growth and the setting of fruit.

With some fruits as the apple, in soils such that application of nitrogen is desirable, the amount of growth and the percentage of flowers to set fruit will be greater if an available form of nitrogen is applied not later than two to three weeks before the time of blooming. Large quantities of nitrogen may be stored in the wood over winter if the nitrogen supply of the soil is abundant in late summer; but applying in one spring sodium nitrate to a soil in which there is little clay or organic matter does not seem to increase the nitrogen content of the spurs of the next spring. Mineral forms of nitrogen when applied in large quantities in an open gravelly soil may be injurious to the trees and particles lodged on leaves may kill them. In sections with very low rainfall, mineral forms of nitrogen, particularly sodium nitrate, may, after seven or eight years of use, have an injurious effect on the trees. Applying nitrogen evenly around the tree in an area no greater than the spread of the branches gives very satisfactory results, at least during five or six years of application, but there is needed evidence as to whether or not application in such a restricted area tends to cause root growth to be limited mainly to that area. The amount of nitrogen that can be applied profitably may be determined by the soil, by whether or not the orchard is in sod, by how early spring cultivation begins, by the price of the fruit concerned, and by the effect of the nitrogen on the coloring of the particular fruit concerned. Iron may nearly always be in an unavailable form in a soil having an alkaline reaction. This may cause chlorosis particularly with some kinds of fruit in some soils. Phosphorus seems to be removed in smaller quantities by fruit crops than by grain crops while potassium seems to be removed in much the larger quantities by fruit crops.

CHAPTER 14

RESPONSES OF DIFFERENT FRUIT-BEARING SPECIES TO APPLICATION OF FERTILIZERS AND TO OTHER PRACTICES IN SOIL MANAGEMENT

Problems such as were discussed in the previous chapter cannot be solved without detailed knowledge as to the peculiar responses of the different kinds of fruit. If in an average soil apple trees make no response to applications of nitrogen, there will be no problem as to the time of applying it or the amount to apply in such average soil. It may seem that a discussion of the results of experiments with fertilizers for the orchard can be of little value, since orchard soils are so variable that results in one orchard could not be applied to another. However, not all crops respond alike to soil treatments, particularly to application of fertilizers, and it should be possible to learn something as to the characteristic responses of different crops, especially if more than one crop is found to have been studied under similar soil and environmental conditions. Generally this has not been done; but in the case of some fruits, such as the apple, with which many soil management studies have been made, it may be possible indirectly to secure some information as to their peculiar responses. If such peculiar responses are known — if it is known, for example, whether or not apple trees will respond in growth to applications of nitrogen in any soil in which corn will show response — such knowledge should be of assistance in deciding as to cultural practices for the apple tree in any soil. Then, through such studies of many field experiments conducted under many different soil and climatic conditions, it should be possible to obtain other information of a general nature. Thus it is often said that strong growth is antagonistic to fruiting. It should be possible to learn whether under average field conditions this is true. If it is true that there is for the tissue a carbohydrate-nitrogen ratio most favorable for fruiting, we should be able to learn for each kind of fruit how great the probability is that, by applying large quantities of nitrogen or by failing to apply nitrogen the tree will be prevented from fruiting well. However, there are in soil-management experiments all the sources of error discussed in the Introduction, and an additional source which is peculiar to soil-management experiments. In some soils, at least, the roots extend so far that, unless the trees are very far apart, those of one plat may obtain material applied to a neighboring plat.

This necessitates the use of buffer rows between the plats. The size of the experimental area is thus increased, and consequently the influence of soil variations is nearly always increased. Since, with these soil-management experiments, the probable error is very large and the danger of misinterpretation of results very great, it seems wise to give more attention to details of method than would be given with other types of experiments.

Results with the Apple

Much more work has been done with fertilizers for the apple than for other fruit crops. For a number of reasons, the difficulties encountered in getting accurate information are very great. Perhaps the most important is that apples are planted farther apart than are other fruits with fewer individuals on an acre. The great age to which the trees live is also an important factor, since the individual differences tend to increase as the trees grow older. The alternate bearing habit of many of the more important varieties brings further complications, since some of the trees in the plats will show this alternating habit more markedly than others.

In Massachusetts. One of the oldest fertilizer experiments in this country was at Amherst, Massachusetts (Brooks, 578, and Shaw, 705). The orchard was on a bench on a hillside with a rather steep slope above and a gentle slope below. A ditch separated the orchard from the forest land above. The trees were planted in 1890, being thirty by forty feet apart, with an additional space of fourteen feet between the plats. In each of the five plats there were three trees of each of four varieties. Crops were grown between the trees during the first five years when the land was seeded down and remained in sod until 1911. From 1911 to 1920 strips eight to twelve feet wide between the rows were kept in cultivation. In Table 26 are given the treatment and the yield to the plat before and after strips of land between the tree rows were cultivated.

TABLE 26. SHOWING TREATMENT AND YIELD OF PLATS AT THE MASSACHUSETTS EXPERIMENT STATION

PLAT	TREATMENT	YIELD BEFORE 1912 (pounds)	YIELD 1912–20 (pounds)
1	Manure 20,000 pounds to the acre..........	31351	45804
2	Wood ashes 2000 pounds to the acre........	17202	38010
3	Check....................................	5348	20702
4	Ground bone 600 pounds and potassium chloride 200 pounds to the acre...............	17843	29730
5	Ground bone 600 pounds and low-grade potassium sulphate 400 pounds to the acre.....	27437	36069

As to trunk growth the plats stand in the same order in which they stand as to yield, the greatest yield being associated with the greatest growth. As to trunk growth and as to yield the strip of cultivated land seemed strikingly beneficial. We should expect this from what we have learned about the effect of sod on the availability of the soil nitrogen.

This experiment is a good one with which to begin our study of plat tests. The table suggests highly beneficial results from all the treatments. However, since there was only one check, and since none of the treatments were given to two plats in different sections of the experimental area, there is no means of determining how much of the difference in growth and yield may have been due to soil variations. Shaw says that early in the life of the orchard the soil, particularly that in plat 3, which is the lowest, was too wet. He does not think that the wetness of the soil in plat 3 was the cause of much of the reduction in growth and yield of that plat. During a visit at this orchard in one spring just before blooming time, the greater wetness of this check plat and part of plats 2 and 4 seemed very striking to me. Aeration of the soil has much to do with growth, especially of young trees. It is interesting to note from tables given by Shaw that, while the trees in plat 3 were much behind those in plat 5 during the earlier years of the experiment, by 1919 trees in plat 3 were yielding nearly as much as those in plat 5. If before 1912 the trees of plat 3 grew slowly and bore small crops on account of lack of potassium, it does not seem probable that, after twenty years of removal of potassium from the soil, the supply would be so abundant that the trees would at the end of the period show improved growth and yield as compared with trees receiving applications of that element. On the other hand, if the soil in plat 5 should be deeper and much better aerated than that in plat 3, the trees in plat 5 would be expected to make much more rapid growth than trees in plat 3. This difference in growth would continue until the tree roots in plat 5 should have come to penetrate thickly nearly all available soil. Since the soil in plat 3 is not wet enough to kill apple roots, trees in that plat also, while growing more slowly from lack of soil aeration, would continue growth until all available soil would be occupied by the roots. If the soil in plat 3 should be heavier and more retentive of moisture, the trees in that plat might eventually become the larger. This would be in agreement with the common observation that trees in an open sandy or gravelly soil may, during the first ten to twenty years of the orchard, grow much more rapidly than trees in a more compact soil, but that later the trees in the compact soil may surpass those in the more open, better aerated, but less retentive soil. The better color and quality of the fruit in plat 5 may have been due to the better aeration of the soil. However, we have seen that there has been a very general opinion that potassium improves the color of fruit.

From what we have learned regarding the effect of sod on the supply of available nitrogen, we can be reasonably certain that the improvement in growth and yield after 1910 was due to an increase in the supply of nitrate nitrogen caused by the cultivation of strips between the rows. It is also reasonably certain that a part of the increased yield in plat 1 was due to the nitrogen in the manure. Since plat 2 with very little phosphorus applied yielded about as much as plat 4 or 5, it seems probable that application of phosphorus was not needed by the trees in this orchard. It is possible that a part of the difference in yield between plat 1 and plat 3, and all of the difference between the yield of plat 2, plat 4, or plat 5 and that of plat 3 was due to potassium applied. On the other hand, it is possible that a part or all of the reduction in growth and yield during the first twenty or twenty-five years of the orchard was due to the greater wetness and the consequent poorer aeration of the soil in plat 3. Before reaching an opinion as to which is the more probable explanation, it seems best to learn what has been the experience of other investigators as to the response of apple trees to application of potassium.

Shaw (705), working with Baldwin apple trees, six years old at the beginning of the experiment, in a rather infertile, sandy loam soil, found manure largely to increase growth of trees in cultivation and of trees in sod, and to reduce fruitfulness during the first two bearing years of the experiment. By the time the trees were twelve or thirteen years old, however, they were yielding as much as were the trees in the other plats. At the beginning of the experiment the trees in the manure plat were the smallest. Combinations of bone meal with potassium chloride or potassium sulphate seemed to increase growth and fruitfulness. As to whether this resulted from the nitrogen in the bone meal or from the potassium, there is not conclusive evidence. In fact, since the differences were not large and there was only one check plat, the evidence that there was any benefit at all from the bone meal and potassium is not convincing.

In New York. Another experiment planned very early was at the New York State Experiment Station, results being published by Beach (564) and Hedrick (621). In this experiment only the effects of phosphorus and potassium were studied. The orchard was in a heavy clay loam soil resting on a heavier clay subsoil, the trees being forty-three years old at the beginning of the experiment and fifty-five at the end. The potassium was applied in the form of wood ashes. After the first five years acid phosphate was applied at the rate of eight and one half pounds to the tree. Analyses of the wood ashes indicated that there were applied 169 pounds of actual potash, and altogether 129 pounds of phosphoric acid to the acre. The results published by Beach (564) for the first five years seemed to indicate some benefit, but the results published by Hedrick (621) for the entire twelve years indicated a very slight apparent benefit. The experimental error with such old trees is so large that, unless the differences were very large, no conclusions should be reached as to the effect of the treatment on yield. There was no apparent difference in color of fruit.

Hedrick (622) published the results of an experiment at the same station conducted during the first fifteen years of the life of an apple orchard. Later Hedrick and Anthony (625) published results during the first twenty years of the same orchard. This was in a heavy Dunkirk clay loam soil, one that was considered good farm land. In it trees make good growth and yield well, but the fruit tends to be small and poorly colored. Great pains were taken to reduce the variation among the trees. Ben Davis trees were planted and budded in the orchard to Rome Beauty, all of the buds coming from one tree. The trees were then shaped to high heads. The orchard was cultivated annually and a non-leguminous cover-crop was used. Manure where used was at the rate of 11,200 pounds to the acre; potassium as potassium chloride, 196, phosphorus as acid phosphate 340, and nitrogen as sodium nitrate 100 and as dried blood 346 pounds to the acre. The materials were spread under the trees extending out a little wider than the spread of the branches. Since the trees, particularly while young, were not occupying nearly all of the soil, the amounts applied to the acre were in reality much larger than the table indicates, being in fact very large.

In spite of the fact that great precautions were taken to reduce the experimental error, individual variation in yield among trees receiving the same treatment were rather large. A large part of this was due to soil differences. Thus, in the southwest corner there was a slight depression where the trees did not grow or bear well. On this account plat 7, a check, was omitted. Plat 8 is apparently reduced in yield by the same depression. There are also other soil differences that are apparent. Thus, in the southeastern part the soil has a higher proportion of clay and the trees yield better. In the north part near a creek there is a silt loam area. Of course, as we have seen in the work of Batchelor and Reed, there may be much soil variation in what seems a very uniform soil. In this glacial soil in particular there may be many soil variations that are not so apparent as those mentioned above, but that may affect markedly the behavior of the trees.

Then it seems probable that, by top-working and training to a high head, the variation among the trees has been increased. It requires a large amount of pruning to obtain a high head, and we shall see that this pruning greatly dwarfs the tree. Neither the amount of pruning nor the injury that young high-headed trees suffer from bending about during early summer would be the same for all of the trees. We should then expect rather marked differences among the trees even if all had had the same treatment as to fertilizers. In Table 27 is shown the yield to the tree in each plat.

Table 27. Yield and Rank of Plats in Geneva, New York, Experiment with Orchard Fertilizers

EAST

NORTH

Plat	Yield to the Tree in Pounds 1902–18		Plat	Yield to the Tree in Pounds 1902–18	
	Yield	Rank		Yield	Rank
Plat 1 Manure..........	4886±202	3	Plat 12 Complete fertilizer	4445±457	7
Plat 2 Phosphorus.......	4649±230	6	Plat 11 Check.........	4395±465	8
Plat 3 Check..	4742±386	4	Plat 10 Phosphorus and potassium......	4728±304	5
Plat 4 Complete fertilizer	5202±284	1	Plat 9 Manure..........	4112±118	9
Plat 5 Check..	3988±148	10	Plat 8 Phosphorus.......	3796±292	11
Plat 6 Phosphorus and potassium......	5026±345	2	Plat 7 Check...........		

SOUTH

WEST

There was no suggestion of benefit except in the west part of the orchard; and in the southwest part unquestionably the yield of the phosphorus plat was low because it was in the depression mentioned above.

This leaves one check, plat 5, with a yield lower than that of the two adjacent plats, one of which received potassium and phosphorus and the other complete fertilizer. Comparing plats 5 and 6, the probable error of the difference (the square root of the sum of the squares of the probable errors given for these plats in the table) is 376 pounds, and the difference 1038 pounds. The difference is thus nearly three times the probable error. The difference between plats 4 and 5 is still greater and the probable error smaller. It should be noted, however, that plat 5 was the smallest yielding check, and plats 4 and 6 the largest yielding plats receiving their respective treatments. It is possible that the soil in a part or all of plat 5 may not have been favorable for trees. Calculating the probable error for the trees of individual plats gives little information as to that. Particularly is this true when there are so few trees to the plat. A careful examination of the yields of individual trees will show that there are differences in yield not due to fertilizer applied that are as great as those between plats 4 and 5, and plats 5 and 6. By using the individual tree yields given in the bulletin, it is possible, by crossing all of the experimental plats except plats 6 and 7, to arrange a series of five tree plats each of which has had the same treatment. In Table 28 is shown the

TABLE 28. SHOWING VARIATION IN YIELD IN POUNDS OF SOME OF THE INDIVIDUAL TREES IN THE GENEVA, NEW YORK, EXPERIMENT

SOUTH

DESIGNATION OF CROSS-PLAT	NPK XII	CHECK XI	PK X	MANURE IX	P_2O_5 VIII	AVERAGE
A	3274	4813	3256	3708	3445	3699
B	6378	6039	5053	3865	3146	4896
C	5493	5534	5331	4162	5263	5156
D	2711	3110	4202	4090	2880	3399
E	4368	2482	5796	4733	4247	4325
Average.........	4445	4396	4728	4112	3796	
F	5100	4971	6166	5482	4002	5144
G	3786	4386	5182	2830	3345	3906
H	5613	5367	4952	5495	4723	5230
I	4996	5081	4726	5665	4013	4896
J	4934	3440	2684	6539	3858	4291
Average.........	4886	4649	4742	5202	3988	
	I MANURE	II P_2O_5	III CHECK	IV NPK	V CHECK	

NORTH

EAST

WEST

total yield during its life of each tree — the trees being arranged as they stood in the orchard, the bottom of the table being north. I have arranged plats crossing the fertilizer plats in an east-west direction and have designated them A, B, C, etc. Thus, the trees of plat A have had the same treatments as those in plats B, C, D, and E, and those in plat F the same as those in plats G, H, I, and J.

It will be seen that the average yield in plats A, D, and G is as much below that of the adjacent plats as that of plat 5 is below that of plats 4 and 6. In other words, differences due probably to soil variations are greater than any attributable to fertilizer treatment, and it seems probable that the apparent benefits in plats 4 and 6 are but the results of soil variation or of differences inherent with the trees.

An attempt was made by Hedrick and Anthony to determine the volume of the top as of a cone. Since Rome Beauty generally forms a conical top, this method seems reasonably accurate except for the fact that the heads of some trees may be much thicker than those of others. The following table shows the average volumes thus found, the average trunk diameters in 1918, and the average tree yields of the different plats.

The trunk diameters were measured at one foot and at three feet above the ground, and the average of those measurements was used. There was

TABLE 29. TRUNK DIAMETERS AND APPROXIMATE TREE VOLUMES — AVERAGE TO THE TREE IN EACH PLAT

EAST

NORTH

PLAT	TRUNK DIAMETER (inches)	TREE VOLUME (cu. ft.)	TREE YIELDS	PLAT	TRUNK DIAMETER (inches)	TREE VOLUME (cu. ft.)	TREE YIELDS
Plat 1 Manure	9.5 ± .11	1491 ± 56	4886	Plat 12 Complete fertilizer	9.0 ± .22	1320 ± 80	4445
Plat 2 Phosphorus	9.6 ± .14	1357 ± 54	4649	Plat 11 Check	9.2 ± .23	1321 ± 85	4395
Plat 3 Check	9.5 ± .10	1535 ± 64	4742	Plat 10 Phosphorus and potassium	9.7 ± .21	1555 ± 91	4728
Plat 4 Complete fertilizer	9.8 ± .23	1624 ± 91	5202	Plat 9 Manure	9.4 ± .12	1255 ± 34	4112
Plat 5 Check	9.0 ± .21	1291 ± 98	3988	Plat 8 Phosphorus	8.7 ± .14	1249 ± 41	3796
Plat 6 Phosphorus and Potassium	10.2 ± .11	1601 ± 92	5026	Plat 7 Check	8.1 ± .24	968 ± 57	..

SOUTH

WEST

not complete correlation between trunk diameter and volume of top or between yield and growth, yet generally the larger yields were on the larger trees. It is interesting to note that the trees that received nitrogen were not larger than the others, and the failure of applications of manure or of complete mineral fertilizer to cause increased yields cannot be attributed to an excessive vegetative growth caused by the use of nitrogen. In fact, the tables indicate no response whatever to the use of nitrogen. This evidence from yield and growth records is supported by the fact that the foliage was generally no greener on the plats receiving nitrogen, and up to the time of publication of the first report (1911) there was no influence of the nitrogen on the color of the fruit, though the variety, Rome Beauty, is one with which color influences can be readily detected.

It is interesting to compare the results of this experiment with those obtained by Jordan and Churchill (639) at the same experiment station in very similar soil. In a rotation of corn, oats, wheat, and grass (timothy on one half and clover on the other), all of the crops showed marked response to applications of phosphorus and nitrogen. The following table shows the yield in dry substances for the different treatments:

TABLE 30. EFFECT OF APPLICATIONS OF NUTRIENTS ON THE YIELD OF CORN, OATS, WHEAT, BARLEY, AND HAY AT THE GENEVA, NEW YORK, EXPERIMENT STATION

PLAT	TREATMENT	CORN (lbs.)	OATS (lbs.)	WHEAT (lbs.)	BARLEY (lbs.)	HAY (lbs.)	TOTAL (lbs.)
1	Farm manure	48.659.9	17,036.3	20.636.5	4,973.3	27,061.8	118,367.8
2	No fertilizer	32,998.1	12,422.4	9,059.8	3,555.1	14,818.4	72,853.8
3	Phosphorus and nitrogen	41,273.0	17,184.7	15,563.5	4,381.1	21,689.6	100,091.9
4	Farm manure	42,932.0	17,898.2	19,311.8	4,206.1	25,211.4	109,559.8
5	Complete fertilizer	45,442.5	19,451.0	20,418.9	4,882.0	23,722.8	113,917.2
6	No fertilizer	34,615.2	12,812.8	9,198.9	3,343.4	10,649.6	70,619.9
7	Phosphorus and nitrogen	40,731.6	14,941.2	14,727.4	3,670.7	14,921.5	88,932.4
8	Complete fertilizer	50,489.0	17,191.3	17,251.5	5,013.0	16,353.1	106,297.9

Plats 1, 2, 3, and 5 with clover in the rotation. Plats 4, 6, 7, and 8 with timothy in the rotation.

During the period from 1897 to 1913 inclusive, plats 3 and 7 received a total of 3050 pounds of acid phosphate, 1200 pounds of dried blood, and 1050 pounds of sodium nitrate, while plats 5 and 8 received 3050 pounds of acid phosphate, 5260 pounds of dried blood, 1975 pounds of sodium nitrate, and 1735 pounds of potassium chloride. Whether the additional response in plats 5 and 8 is due to the additional nitrogen or to the potassium chloride, we cannot say. It seems highly probable that at least a part of it is due to the increased nitrogen supply. The table strongly suggests that there was a marked response to the use of phosphorus, though we cannot be certain as to this, since no plat received phosphorus alone. Certainly either nitrogen or phosphorus has caused response, and both seem to have done so. Yet in the experiment with apple trees the elements that most certainly have not caused response are phosphorus and nitrogen. It seems, then, that in so far as nitrogen and phosphorus are concerned, apple trees may obtain enough of these elements for maximum growth and production in a soil where the available supply is too small for maximum production of corn, oats, wheat, and grass. In some clay soils the phosphorus often becomes unavailable, even though there may be large quantities in the soil. It is possible that apple trees have to a greater extent than have other crops the ability to use the phosphorus in this insoluble form, or that they draw upon larger soil masses for the necessary elements.

As to nitrogen in the experiment with apple trees, it might be held that, even though the growth of the tree or the size of the fruit should not be influenced by the applications, the percentage of blossoms which set fruit might be influenced favorably or unfavorably by it. In that case the effect might not be realized unless the application were made a few weeks before the bloom. The applications in this experiment were made generally as soon as the soil could be ploughed in spring. Whether or not this was before the bloom the records do not say. It might be held by some who stress the importance of the carbon-nitrogen ratio in the setting of fruit that, if the nitrogen had always been applied a few weeks before the bloom, it might have increased the percentage of blossoms setting fruit by bringing the nitrogen to the optimum, or it might have decreased the percentage of blossoms setting by bringing the nitrogen too high in proportion to the carbohydrates. If this had been true, however, there should have been excessive vegetative growth. Yet the amount of growth was not influenced by the nitrogen. Then in the manure plats, and probably in plats to which dried blood was applied, nitrogen would accumulate; and so if the orchard were cultivated there would always be an abundance in the soil at blooming time. Yet neither manure nor blood seemed to influence growth or yield. Apple trees have not made any apparent response to applications of nitrogen in this soil, and the failure to respond can hardly be attributed to the time of application.

This soil is one very high in total potassium, and, even if it should be found that under average soil conditions fruit trees show a peculiar response to applications of potassium, it is not surprising that trees in this soil showed no response. However, if potassium should strikingly influence the color of fruit, either the apples of this orchard should be highly colored or applications of potassium should improve color. As a matter of fact, apples in this orchard tend to be poorly colored, and yet application of potassium does not improve color. None of the treatments seemed to influence the size of the fruit.

Collison (587) and Collison and Harlan (589) studied the responses of mature apple trees, in two orchards in well-aerated loam soils in western New York, and the responses of young apple trees, in a less retentive gravelly loam in northern New York to applications of nitrogen, potassium, and phosphorus. There was with the mature trees no convincing evidence of any benefit as to yield or growth caused by any treatment. With the young trees some of the treatments seemed to increase growth; but the results of different treatments were so inconsistent that no conclusions seem justified. Lyon, Heinicke and Wilson (664) at Ithaca, New York, have tested the effect on the growth of young apple trees in sod and in cultivation of applications of 100, 300, and 900 pounds of sodium nitrate to the acre. All of the experimental area was fertilized uniformly with potassium and phosphorus. The soil was a retentive Dunkirk clay loam. They used McIntosh apple grafts that had grown one year in the nursery. These were set four feet apart each way and were cut off at the surface and weighted in the spring of 1921 when they had been growing four years. The results are shown in Table 31.

TABLE 31. THE EFFECT OF APPLICATIONS OF SODIUM NITRATE ON CLOSELY PLANTED YOUNG APPLE TREES IN SOD AND TREES UNDER TILLAGE WITH A RYE COVER-CROP

SODIUM NITRATE APPLIED (pounds)		TIMOTHY SOD	CULTIVATION RYE COVER-CROP
To the acre	To the tree	Average weight of trees (grams)	Average weight of trees (grams)
0	00	1404± 73	4703± 30
100	0.05	1328± 91	4861±134
300	0.15	1602±130	5023±132
900	0.45	3054±251	5014± 78

Each weight given in the table is the average of three or four plats of twenty trees each. Duplicate plats having each treatment were evenly distributed over the experimental area. In sod the trees made very great response to applications of nitrate nitrogen. There may have been slight response in the cultivated plats, but the differences are not conclusively significant. It would seem that by far the best means of testing the response of trees in growth would be by the method of this experiment using plats of rather closely planted trees and digging them up and weighing them; several plats with each treatment being systematically distributed over the experimental area.

At the same experiment station young Henry Clay apple trees closely planted in a light sandy soil very low in nitrogen failed to show any response to applications of nitrogen, though they were planted in the same positions in which peach trees showed response of about thirty per cent in growth, and cherry trees in adjoining plats showed very marked response, about forty per cent increase in growth. Young Delicious apple trees growing during three years in an adjacent planting, but in a heavier soil, a Dunkirk clay loam, failed to respond to applications of phosphorus; while in the same soil, in rows immediately adjoining those of the apple trees, maize showed an increase in green weight of 160 to 300 per cent as a result of the same treatment. These Delicious apple trees showed no significant response to applications of nitrogen alone or in combination with phosphorus, though raspberries in adjoining rows in the same soil type showed marked response to applications of nitrogen, whether alone or in combination with phosphorus; and oats, rape, and maize showed no response to applications of nitrogen without phosphorus but showed some response when phosphorus also was added. There is a suggestion from the records that these Delicious apple trees may have made a small increase in growth as a result of applications of potassium chloride; but the evidence is not conclusive.

In Pennsylvania. Many different experiments in which fertilizers were involved were conducted by Stewart (712) in orchards in different parts of Pennsylvania. Generally there were ten trees to each plat. The fertilizer was used at the rate of fifty pounds of actual nitrogen, carried in a combination of about equal parts of sodium nitrate and dried blood; one hundred pounds of actual phosphorus pentoxide in the form of acid phosphate unless otherwise stated; one hundred and fifty pounds of potash (K_2O) in the form of potassium chloride unless otherwise stated. Manure was used at the rate of twelve tons to the acre, and lime at the rate of one thousand pounds.

Anthony and Waring (555) have made the latest report concerning most of Stewart's experiments and have tried to determine statistically which results were significant. The results from a number of the orchards are shown in Table 32.

TABLE 32. THE EFFECT OF APPLICATION OF VARIOUS COMBINATIONS OF MINERAL NUTRIENTS ON THE YIELD OF APPLE ORCHARDS IN PENNSYLVANIA

TYSON ORCHARD

PLAT	TREATMENT	POUNDS TO THE TREE		GAIN OVER CHECK	
		YORK IMPERIAL	STAYMAN	YORK IMPERIAL	STAYMAN
16	Check.	3332±272.3	1559±142.9		
15	N.P.K, 1912.	3714±522.4	2549±456.6	382±589.0	990±478.4
14	Manure.	3881±346.5	3697±559.1	494±570.2	18±587.3
13	Check.	3387±452.9	3679±180.0		
12	Raw Rock, N.P.K. 1912.	3731±281.5	3653±188.5	344±533.2	−26±260.6
11	Acid Rock, N.P.K. 1912.	3732±337.6	3148±377.0	344±424.1	1300±394.6
10	Check.	3388±256.8	1848±116.5		
9	Nitrogen.	3235±323.9	2206±290.1	−153±413.3	358±312.6
8	N.P.K.	4218±427.5	3207±287.6	1648±494.5	411±536.3
7	Check.	2570±248.7	2796±452.7		
6	P-K_2SO_4.	4721±246.2	2704±280.1	2151±349.8	−92±532.3
5	P-KCl.	4589±491.3	2470±295.1	974±706.9	−47±381.3
4	Check.	3615±508.3	2517±241.6		
3	N & K.	4652±244.3	3439±696.1	1037±563.9	922±617.5
2	N. & P.	4155±345.1	2452±155.9	762±379.3	−632±430.3
1	Check.	3393±157.5	3084±401.1		

WERTZ ORCHARD

PLAT	TREATMENT	POUNDS TO THE TREE		GAIN OVER CHECK	
		YORK IMPERIAL	JONATHAN	YORK IMPERIAL	JONATHAN
1	Check.	3980±358	4612±227		
2	N-P.	3686±285	5103±288	−294±458	491±367
3	N-K.	3804±261	4388±405	−513±526	−472±451
4	Check.	4317±457	4860±198		
5	P-K Cl.	4025±605	4605±210	−292±758	−255±289
6	P-K_2SO_4.	2893±244	5154±176	40±573	1275±388
7	Check.	2853±518	3879±346		
8	N-P-K.	4937±590	4910±148	2084±785	1031±376
9	N.	4174±257	5186±301	−1422±342	1251±381
10	Check.	5596±227	3935±234		
11	Acid Rock N-P-K '12.	4605±629	4976±399	−991±669	1041±462
12	Raw Rock N-P-K '12.	4651±550	3426±391	1753±764	−192±697
13	Check.	2898±531	3598±577		
14	Manure.	4712±205	4223±229	1814±569	625±621
15	Lime N-P-K '12	4054±183	3817±418	464±790	156±478
16	Check.	3590±768	3661±232		

TABLE 32. THE EFFECT OF APPLICATION OF VARIOUS COMBINATIONS OF MINERAL NUTRIENTS ON THE YIELD OF APPLE ORCHARDS IN PENNSYLVANIA (*continued*)

BROWN ORCHARD

PLAT	TREATMENT	AVERAGE YIELD TO THE TREE IN POUNDS
16	Check	428± 76
15	Lime and N-P-K, 1912	2082±130
14	Manure	4172±395
13	Check	1802±180
12	Raw Rock, N-P-K, 1912	1955±131
11	Acid Rock, N-P-K, 1912	1903±109
10	Check	1491±139
9	Nitrogen	2410±114
8	N-P-K	3181±776
7	Check	1527±175
6	P-K_2SO_4	1426±243
5	P-KCl	1639±119
4	Check	855± 79
3	N-K	4187±237
2	N-P	6682±301
1	Check	2771±161

JOHNSTON ORCHARD

PLAT	TREATMENT	AVERAGE YIELD TO THE TREE IN POUNDS	GAIN
1	Check	2567±206	
2	N-P	4579±278	2012±346
3	N-K	4244±178	1592±288
4	Check	2652±227	
5	P-K	2813±191	161±297
6	N-P-K	4275±340	1764±502
7	Check	2511±369	
8	Manure	4841±142	2330±395
9	Lime and N.P.K.	3227±186	1246±221
10	Check	1981±120	

The soil of the Tyson orchard has been classified as Penn gravelly loam, and both chemical analysis and experience with crops grown upon it indicate that in it the supply of mineral nutrients is high as compared with other soils. The orchard was cultivated each year and a cover-crop was sown. The trees were planted in 1900, and were thus in their nineteenth season when the last records reported by Anthony and Waring were taken. There were alternate pairs of rows of York Imperial and York Imperial top worked to Stayman at five years of age. There were five trees of each variety to the plat. There is a difference of nearly twenty feet in elevation in the orchard; and the yield was greater in the lower elevations. On this account the experimental error is large. With York Imperial trees, plats 6 and 8 seem to show significant differences in yield over the checks, while with Stayman trees only plat 11 showed a difference that approached being significant. Anthony and Waring, using "students" formula, comparing each tree in a treated plat with the nearest tree in the nearest check, found that the odds were 284 to 1 that the phosphorus and potassium sulphate in plat 6 increased the yield of York Imperial trees, the odds for the other plats being rather small. Doubt is cast upon the conclusiveness of any of these results, when some of the inconsistencies are considered. In plat 6, although with York Imperial trees the odds appear so large that potassium or phosphorus or both caused a better yield, Stayman trees yielded less than was yielded by the checks, with plat 11 in which fertilized Stayman trees showed the greatest yield as compared with the nearest check, York Imperial trees yielded but slightly more than the checks. It is reasonably certain that in this rather fertile soil with cultivation and a cover-crop neither nitrogen nor phosphorus has caused an increase in yield and (Stewart, 712), apparently neither has caused an appreciable increase in growth. The plats showing increases in yield, that may be significant, all had potassium applied, and so there is a slight suggestion that potassiun has been beneficial to the trees in this experiment. The results are very uncertain, however, largely because so many different treatments were tried that it was not possible to have enough distributed plats having each treatment.

The Wertz orchard also was cultivated and a cover-crop was sown annually. The land is nearly level and the soil, a Mont Alto loam, is much below the average in fertility as indicated by crops grown and is low in mineral nutrients as indicated by chemical analysis. It is sandy at the surface with rather compact red clay at varying distances beneath the surface. The trees, York Imperial and Jonathan, were eight years old when the experiment was started. And peach trees used as fillers in the orchard had been rather heavily fertilized with bone meal and potassium sulphate. Nitrogen alone seemed to reduce the yield of York Imperial, but to increase that of Jonathan. Potassium sulphate seemed highly beneficial to Jonathan, but of no value to York Imperial. These and other inconsistencies and the large probable errors indicate that there is no convincing evidence of benefit from any treatment. And there may be differences between plats concerning which the probable error, calculated from the yield of individual trees in each plat, gives no information. Thus, Anthony and Waring studied the yields of parallel rows of five trees each, the rows crossing the fertilizer plats, trees having the same treatment thus being compared with each other. Yet with Jonathan the average yield to the tree was, in one of the rows, 2115 pounds greater than in the other with odds by "students" formula of 122 to 1 that the difference was significant; and with York Imperial the average yield to the tree in one row was 3011 pounds greater than in the other with odds of 199 to 1. Certainly in this experiment the difference in yield due to influences other than the fertilizer treatment were much greater than any difference due to a treatment. Odds of 200 to 1 or greater are not convincing either in this or the Tyson orchard. We cannot say, however, that none of the treatments were beneficial. We can say only that if any treatment was beneficial the benefit was not large enough to be found under the conditions of the experiment. However, it is of value to know that, in this soil of low fertility for field crops, apple trees may make good growth and bear excellent crops without the application of any mineral nutrient; for the average annual yield from the time the trees were nine to the time they were eighteen years old was 179 to 264 bushels to the acre on the checks. Only in the manure plat was there an increase in growth that was almost certainly due to the fertilizer, and in this the evidence is stronger than in any other, except plat 8, that there is an increase in yield due to the treatment.

The Brown orchard planted in 1888 was located on a steep hillside in a very stony soil, and was in sod. Both manure and sodium nitrate combined with dried blood were very beneficial. Other elements than nitrogen seem not to have been beneficial. The variability in yield was rather great, however, and a small response could have been hidden by the experimental error.

The Johnston orchard, planted in 1889, was in a Volusia silt loam soil that was level and rather uniform, and was in sod. Nitrogen was very beneficial, but the data suggest rather strongly that no other element influenced the yield. Nitrogen very greatly increased growth also.

Anthony and Waring give the results of another experiment in which the response to fertilizers and to cultural methods was studied in a soil of the same type as that in the Wertz orchard, though there was more variation in contour. The trees, of York Imperial and Baldwin, were planted in 1895. The commercial fertilizer used carried thirty pounds of nitrogen in sodium nitrate and dried blood, sixty pounds of phosphorus pentoxide, and one hundred pounds of potash (K_2O). The manure in the amounts applied contained much larger quantities of these elements. The results are shown in Table 33.

Table 33. The Influence of Cultural Methods and of Fertilizers on the Yield of York Imperial and Baldwin Apple Trees

Plat	No Fertilizer		Manure	Commercial Fertilizer	Culture
	Variety	Yield	Yield	Yield	
	York Imperial	1360±137	2701±177	2001±230	Sod
	Baldwin	1078±180	1796±138	1703±247	Sod
	York Imperial	1998±165	2679±247	2820±181	Mulch
	Baldwin	2129±198	2353±291	2612±593	Mulch
	York Imperial	2024±193	2363±105	2094±214	Tillage and Cover
	Baldwin	2462±138	2185±229	2237±504	Tillage and Cover
	York Imperial	1986±180	2231±168	2959±107	Tillage
	Baldwin	1747±226	1691± 85	2959±257	Tillage

While the variability is rather large, we can say with reasonable certainty that both manure and commercial fertilizer have increased the yield in the sod plats and apparently in the mulched plats. In the plats receiving tillage and a cover-crop there has been little or no benefit from manure or fertilizers. The highest yielding plat in the orchard is that which had tillage and commercial fertilizer with no seeded cover-crop, but a heavy growth of weeds. The soil of this and of the fertilized mulched plat was better than that of the other plats; while the soil of the fertilized tillage and cover-crop plat and that in the fertilized sod plats was less retentive than that of the others. The growth of weeds in the plat which had tillage with neither fertilizer nor a seeded cover-crop was very slight; and Anthony and Waring think that the trees in that plat are showing indications of a decline in vigor. The results suggest that very slight harm may follow neglect of a cover-crop during seven or eight years, particularly if there is a good growth of weeds. Since the fertilizers were beneficial only with cultural practices that would lower the supply of available nitrogen it is probable that only the nitrogen in the fertilizer application has benefited these trees. In other words, in soil so low in available nutrients that weeds will make very little growth without application of fertilizers, apple trees in cultivated soil have been able to obtain enough mineral nutrients for satisfactory growth and fruitfulness and have not responded to applications of any nutrients.

In a number of Stewart's experiments there were plats to test the response of apple trees to the different compounds used for the potassium or the phosphorus contained. For example, potassium sulphate was compared with potassium chloride and acid phosphate with basic slag and floats. However, since the experimental error was so large that it was not possible to determine with certainty whether or not in these soils apple trees responded to applications of potassium or phosphorus in any form, it is evident that the experiments give no information as to the relative value of different carriers of these elements. In Table 34 is given an estimate prepared by Stewart as to the influence of application of the various mineral nutrients on tree growth and yield and on color and size of the fruit.

TABLE 34. STEWART'S ESTIMATE OF THE INFLUENCE OF FERTILIZER ELEMENTS ON TREE GROWTH AND YIELD, AND ON COLOR AND SIZE OF FRUIT

(Calculated average benefits in six experiments during ten years)

	YIELD 1908–17 (Per cent)	COLOR 1908–17 (Per cent)	SIZE 1908–17 (Per cent)	INCREASE IN TRUNK GIRTH 1907–16 (Per cent)
(*a*) Experiments 215, 216, and 220				
Nitrogen in combination	49.6	−16.0	− 0.1	12.5
Nitrogen alone	24.7	−21.0	− 1.3	17.2
Phosphorus in combination	14.5	− 2.9	1.5	− 0.3
Phosphorus alone (1908–12)	−10.7	2.7	− 0.6	2.4
Potash in combination	10.7	2.1	6.7	0.8
Complete fertilizer	65.6	−16.9	1.3	18.9
Manure	73.0	−18.9	4.4	25.2
Lime alone (1908–12)	− 8.2	− 0.3	− 2.0	6.3
Lime (and NPK, 1913–17)	53.4	−10.1	4.3	31.6
(*b*) Experiments 336, 338 and 339				
Nitrogen in combination	50.7	−15.8	5.1	25.8
Phosphorus in combination	13.0	− 5.6	2.0	− 4.7
Potash in combination	7.0	− 0.3	− 1.1	4.3
Complete fertilizer	66.2	−25.7	3.7	26.9
Manure	108.8	−37.2	8.5	39.3
Lime alone (1908–12)	29.8	− 5.4	15.9	15.5
Lime (and NPK, 1913–17)	52.7	−29.7	0.6	38.4

From what we have just learned, it is evident that these differences in yield and growth may not all be due to difference in mineral nutrients applied. The only significant differences are due to applications of nitrogen, in manure or otherwise; and the large increases following application of nitrogen are due to the fact that some of the orchards were not cultivated. The highest yields have generally been associated with the most rapid growth. Waring (15) from an even more careful analysis has shown that in these experiments the degree of correlation between growth and yield is very high indeed.

The results as to color should be somewhat more dependable than results as to yield, since variation in the size of the trees would generally influence color but little. It is reasonably certain that only fertilizer carrying nitrogen perceptibly influenced color. Nitrogen, by causing increased growth and, therefore, the growth of more foliage to shade the fruit, reduced color. It is possible that color may have been reduced somewhat also by a delay in maturity of the fruit.

The table suggests that the fertilizers have not had an apparent influence on the size of the fruit. If the nitrogen should tend to cause the fruit to be larger, that influence might be offset by the increase in the number of fruits to the tree.

In New Hampshire. Pickett (682a) and Gourley (610–612) have published the results of an experiment in New Hampshire in a sandy soil that permits deep penetration of the roots. Analyses suggest that the soil was low in phosphorus, but well supplied with potassium. The trees were Baldwin, set thirty-five feet apart, and were twenty-five years old at the beginning of the experiment. The orchard had been so neglected that it had not produced profitable crops. The trees had suffered severe winter injury two years before the experiment began. There were trees missing from the orchard; more from some plats than from others. It is evident that trees around the area from which trees were missing might be expected to yield more than the others, since the lower branches would be less injured by shade. One plat received tillage alone, another tillage and crimson clover or mixed clover cover-crop, and others tillage, crimson clover or mixed clover cover-crop, and applications of nitrogen, potassium, and phosphorus. The normal amounts of fertilizer used were two pounds of sodium nitrate, four pounds of potassium sulphate, and eight and a half pounds of acid phosphate to the tree. In plat 8, seventeen pounds to the tree of acid phosphate were used; in plat 9, six pounds of sodium nitrate, and in plat 10, ten pounds of potassium sulphate. Gourley and Shunk (614) found that in all plats receiving nitrogen there was more nitrate nitrogen both in the surface soil and in the subsoil than in the soil of other plats. There was also more nitrate nitrogen in the soil in the plat on which a leguminous cover-crop alone was used than in soil in the plat having no cover-crop. Throughout the experiment the trees in fertilized plats, and particularly those in the plat receiving more nitrogen, made slightly more growth than was made by the others; but only beginning in 1916 were the leaves of a greener color in the plats receiving nitrogen. From that year the trees in all plats receiving nitrogen, and particularly those in plat 9 which received the most nitrogen, had larger greener foliage, and appeared in every way a little more vigorous than the trees in plats to which no nitrogen was applied. This increased vigor and growth were not associated with an increased yield. The average yield to the tree in these plats is shown in Table 35.

TABLE 35. AVERAGE ANNUAL YIELD IN POUNDS TO THE TREE, NEW HAMPSHIRE EXPERIMENT

YEAR	CLEAN CULTIVATION	CULTIVATION WITH COVER-CROP	CULTIVATION WITH NPK	CULTIVATION WITH NPK	CULTIVATION WITH NPK + P	CULTIVATION WITH NPK + N	CULTIVATION WITH NPK + K
	4	5	6	7	8	9	10
1909	26	21	15	18	20	23	8
1910	451	634	496	518	450	455	612
1911	122	29	77	35	52	42	29
1912	459	501	506	462	400	401	364
1913	100	27	41	14	33	23	27
1914	669	647	682	568	477	657	664
1915[a]							
1916	467	472	416	301	339	336	530
1917	46	21	68	73	108	155	68
1918	283	330	284	119	111	106	107
Average	262	268	258	210	199	219	240

[a] Crop destroyed by frost.

In this experiment increase in growth has not, so far as one is able to determine, been accompanied by an increased yield. In so far as trunk girth records indicate, the trees in plat 9 which received the most nitrogen are also the larger, and yet have yielded less than those of plat 5, which have received only cultivation with cover-crops. In 1910, however, when the first good crop was borne, that of plat 5 was appreciably larger than that of plat 9. The variation in yield of trees in a plat was very large. Whether this was due to differences in the amount of shade or to the amount of winter injury, or to something else, we cannot say; but certainly the experimenal error involved is so large that one is not justified in concluding that additional growth, apparently caused by the nitrogen, has been unfavorable to fruitfulness. It is possible, though of course not certain, that the additional growth in plat 9 may have been even slightly beneficial as to yield of fruit, but that in plat 5 other favorable conditions may have increased the yield. There were more missing trees in plats 4, 5, and 10 than in plat 9. This may have increased fruitfulness by reducing the amount of injury to the lower branches from shade or by making available for some of the trees a larger area of soil from which to obtain water and mineral nutrients. Since the experimental error is so large, it is hardly certain that potassium or phosphorus has not been beneficial. Such a benefit certainly could not be large, however, and the conclusion that no profitable benefit can have followed the use of any fertilizers in this experiment seems to be justified. It is interesting to compare the results of this experiment with those from the Tyson orchard in Pennsylvania. Neither orchard was very uniform, and if we must conclude that potassium has increased the yield in the Tyson orchard, then we have in Gourley's results almost as conclusive evidence that potassium and phosphorus with small or large amounts of nitrogen have been injurious. It seems probable that in both cases the differences in yield have resulted from other causes than the application of the fertilizers. It should be said that recent reports by Potter from the New Hampshire Experiment Station indicate that the application of nitrogen is now proving very beneficial in this orchard.

In Maine. Woods (738) published results of experiments in Maine to determine the response of Baldwin apple trees to applications of nitrogen and of Ben Davis apple trees to applications of complete fertilizer, both in cultivation with a non-leguminous cover-crop. The soil he describes as shallow, with a stubborn subsoil. During the five years from 1913 to 1917 there was no measurable response.

In Ohio. Ballou (558–560) has published results of a considerable number of experiments with the use of fertilizers in unproductive hill soils in Ohio. Most of the orchards were in sod. Nitrogen alone was used in some plats and nitrogen with phosphorus or potassium or both in others. Applications of potassium or phosphorus seemed to cause no response whatever. Ballou gives no direct evidence as to the supply of potassium and phosphorus in the soil except that it is an extremely poor upland soil, and one in which clovers respond markedly to applications of acid phosphate. As to the effects of nitrogen, not only growth was markedly increased, but fruit-bud formation also. In the first year of the experiment, if the nitrogen was applied early the blossoms set fruit; while little fruit was left on unfertilized trees after the June drop.

Ballou (561) reports results of one experiment in southeastern Ohio, in which half of the series was in cultivation. There were twelve trees to the plat, four Ben Davis and eight Rome Beauty. The orchard had been notoriously unfruitful. The fertilizer was applied two weeks or more before the bloom. Nitrogen was effective in increasing the percentage of flowers to set in the first year. Table 36 shows his results during five years.

TABLE 36. ANNUAL YIELD TO THE TWELVE-TREE PLAT IN THE BENEDICT ORCHARD, VINCENT, WASHINGTON COUNTY, OHIO

CULTIVATED PLAT	1914 (lbs.)	1915 (lbs.)	1916 (lbs.)	1917 (lbs.)	1918 (lbs.)	5-YEAR AV. (lbs.)
Nitrate of soda 5 lbs. on tree circle	3309.0	3316.8	3134.1	2801.4	3539.0	3220.1
Nitrate of soda 5 lbs. on tree square	2642.5	3355.2	3242.1	3306.0	2540.0	3017.2
No fertilizer	1467.7	3073.9	2414.6	2505.6	1892.1	2270.8
Nitrate of soda 5 lbs.; acid phosphate 5 lbs. on tree circle	2480.0	3768.3	2871.0	2644.8	3644.1	3081.6
Nitrate of soda 5 lbs.; acid phosphate 5 lbs. on tree square	2229.3	4256.4	2396.7	2296.8	3574.0	2950.6
No fertilizer	1631.5	2751.3	2111.8	2575.2	2470.0	2308.0
Nitrate of soda 5 lbs.; acid phosphate 5 lbs.; muriate of potash 5 lbs. on tree circle	2253.4	5650.5	2703.4	3567.0	3504.0	2935.7
Nitrate of soda 5 lbs ; acid phosphate 5 lbs.; muriate of potash 5 lbs. on tree square	1950.0	3838.1	3462.4	3862.8	3924.4	3407.5
GRASS-MULCH PLAT						
Nitrate of soda 5 lbs. on tree circle	1344.6	4767.6	2203.4	3636.6	2137.4	2817.9
Nitrate of soda 5 lbs. on tree square	1605.3	3291.7	1325.5	2852.6	2402.2	2295.5
No fertilizer	1652.1	1003.8	1734.6	1131.0	1997.2	1503.7
Nitrate of soda 5 lbs.; acid phosphate 5 lbs. on tree circle	3178.0	4377.8	2730.0	4297.8	4415.0	3799.7
Nitrate of soda 5 lbs.; acid phosphate 5 lbs. on tree square	3111.8	3265.8	3130.5	3828.0	4870.5	3641.3
No fertilizer	1301.1	2067.3	1501.0	2035.8	1962.2	1773.5
Nitrate of soda 5 lbs.; acid phosphate 5 lbs.; muriate of potash 5 lbs. on tree circle	2309.8	3799.8	2752.1	3984.6	3591.6	3287.6
Nitrate of soda 5 lbs.; acid phosphate 5 lbs.; muriate of potash 5 lbs. on tree square	4292.4	2731.8	3005.7	3619.2	5606.4	3851.1

There was marked response to applications of nitrogen, both by trees in sod and those in cultivation, though the response in sod was much the larger. In the cultivated part there is no indication that any element but nitrogen influenced the yield. In the sod plat, however, phosphorus seems to have increased the yield. This element greatly increased the growth of red and white clover in the sod. Since the phosphorus apparently did not increase the yield of the trees in cultivation, it seems probable that the increase with the sod trees is due to this effect of phosphorus on the amount of clover in the sod. This clover would tend to increase the total nitrogen supply; and we have seen that the supply of nitrate nitrogen is reduced by clover sod less than by a grass sod. Ballou reports the results of other experiments where nitrogen markedly increased the yield of trees in sod, and where phosphorus increased the yield apparently by increasing the growth of clover that supplied nitrogen.

In Oregon. Lewis (653), Lewis and Brown (655), and Lewis, Reimer, and Brown (656) report work with the effect of fertilizers on apple trees in light fruit soils of Hood River, and other parts of Oregon, that, through continuous cultivation, or due to some other influence, become very greatly depleted in nitrogen. The supply of potassium and phosphorus was probably rather high. The trees had become very weak and had ceased to bear fruit of normal size. Applications of sodium nitrate as a spray on the trees was first tried. Such a method was used as a result of the work of Ballard and Volck (557) in California, where winter spraying with a solution of sodium nitrate seemed to give markedly beneficial results. It was soon found, however, that applying nitrate to the soil gave satisfactory results. Trees so fertilized showed very marked improvement in growth; and in some cases fruitfulness was increased as much as tenfold. The size of the fruit was also increased. Applying the sodium nitrate about a month before bloom greatly increased the percentage of flowers to set fruit. In some soils rather large applications of nitrogen appreciably reduced the color of red fruits, but, apparently, not the tendency to set enough fruit buds. The use of a leguminous cover-crop or of a leguminous permanent crop (alfalfa) tended to supply nitrogen enough to cause good results; though additional nitrogen seemed necessary in some soils. Additions of potassium, phosphorus, or lime did not seem to give beneficial results.

In England. Dyer and Shrivel (597), working in England with what they describe as a poor clay loam of a light color resting upon a deep bed of heavy clay, did some work with apple trees. The only striking result obtained was with the omission of potassium. In that plat both tree growth and yield were conspicuously low. Since only one plat received no potassium, it is possible that the trees in that plat were poor for some other reason; but the indications are that in that soil application of potassium was beneficial.

Of much interest is the work done by Pickering (681) in England. In the Ridgmont soil, which he describes as a shallow soil overlying an Oxford clay, one in which trees make very shallow root systems, he ran a series of experiments mainly to test the effects of large and small quantities of manure and of artificial fertilizers. The series generally contained plats receiving what he termed normal treatment, twelve tons of manure to the acre or its equivalent in mineral fertilizers; plats receiving more than normal, sometimes as high as thirty tons of manure or ten times the normal amount of mineral fertilizers; and plats receiving less than normal to no fertilizer. It does not seem necessary to give his tables, since he does not give individual tree yields or probable errors. His results indicate strongly that the fertilizer did not influence either growth or fruitfulness of the trees. In this same soil Pickering tried the same treatments on onions and potatoes. With both of these crops beneficial results were obtained from the use of fertilizers, those plats on which more than the normal amount of either manure or of mineral fertilizers was used giving decidedly the best results. Considering the mean for all his experiments for onions and potatoes, when the yield of plats receiving no fertilizer is considered as 100, that from plats receiving artificial fertilizers equivalent to twelve tons of manure is 106; that for plats receiving artificial fertilizers equivalent to thirty tons of manure, 126; that for plats receiving twelve tons of manure, 124; that for plats receiving thirty tons of manure, 122. Thus, in a soil shallow enough for the tree roots to be unable to obtain mineral nutrients by penetrating to a much greater depth than the roots of annual crops penetrate, and one so infertile that onions and potatoes show a marked response to applications of complete fertilizers, no response at all is shown by apple trees.

In a very coarse sandy soil at Millbrook, so infertile that it had long been abandoned for agricultural purposes, very marked beneficial results followed applications of as much as twenty-four tons of manure to the acre. Each plat contained twenty trees on Paradise stock (ten Cox's Orange and ten Potts's seedling). There were fifteen plats, three of which received artificial fertilizers equivalent to twelve tons of manure; and, as at Ridgmont, the others received either more or less than this normal amount. Table 37 shows the relative results obtained, considering results with no fertilizers as 100.

TABLE 37. EFFECT OF FERTILIZERS UPON FRUIT TREES GROWING IN AN UNPRODUCTIVE SOIL AT MILLBROOK, ENGLAND

	NO FERTILIZER	ARTIFICIALS			MANURE		
		Single	Double	Treble	Single	Double	Treble
Prunings	100	147	125	163	151	213	227
Weight of crops	100	141	142	168	156	186	242
Size of fruits	100	132	142	163	191	272	251

It is interesting to note that both the amount and the size of the fruit were greatly increased. In some of his work tests were made as to the effect of omitting one element. Table 38 gives relative results when complete fertilizer is considered as 100.

TABLE 38. EFFECT OF OMITTING ONE ELEMENT ON THE YIELD AND GROWTH OF FRUIT TREES IN AN UNPRODUCTIVE SOIL

	NO MANURE	POTASSIUM OMITTED	PHOSPHATE OMITTED	NITROGEN OMITTED	COMPLETE MANURE
Weight of prunings.......	68	65	121	103	100
Weight of crops..........	71	37	111	98	100
Size of fruits............	76	99	120	108	100

It will be seen that when potassium is omitted no better results are obtained than when no fertilizer is used. Since only one plat of twenty trees receiving no phosphorus is involved, the greater growth and yield on that plat seems more likely to have been due to soil variation than to an injurious effect of phosphorus in the other plats. Analyses for available potassium indicate that the soil was exceedingly low in that element (0.006 per cent), though it was not low in phosphorus, and there was 0.1 per cent of nitrogen in the top nine inches.

In West Virginia. Alderman and Crane (553) studied the effect of fertilizers on apple trees in several orchards in West Virginia. One, known as the Reynolds orchard, was of Rome Beauty trees twenty years old at the beginning of the experiment in 1911. The soil, known as a Dekalb silt loam, was so poor that, at the beginning, it supported only a very meager growth of grass and weeds between the trees. The trees were in a very badly devitalized condition. During most of the experiment the orchard was under cultivation. In the years 1911, 1912, 1914, and 1917 a cover-crop of cowpeas was grown; in 1918 and 1919, it was in clover sod; in the other years, the cover-crop was of weeds. The fertilizer was usually applied early in May. Unfortunately, a record of tree-trunk circumference was not taken until 1916. Measurement, in some of the check trees and some receiving complete fertilizer, showed that the application of complete fertilizer greatly increased shoot growth and that in the check plats cultivation caused increased growth as compared with that of previous years. In Table 39 is shown the yield and the trunk growth (in so far as measurements were taken) of the trees receiving each treatment.

In 1911 and in 1913 no crop was borne. Not counting these years, the average annual yield to the tree was only about six to fifteen bushels.

TABLE 39. EFFECT OF DIFFERENT FERTILIZER TREATMENTS ON THE GROWTH AND YIELD OF APPLE TREES IN A POOR BUT TILLED SOIL IN WEST VIRGINIA

PLAT	TREATMENT	POUNDS TO THE ACRE	AVERAGE TRUNK GIRTH INCREASE (inches)	TOTAL YIELD IN SEVEN BEARING YEARS TO THE PLAT OF SIX TREES (bushels)	AVERAGE PER CENT OF A FULL BLOOM 1915 TO 1919
1	Potassium chloride.. Acid phosphate.....	100 375			
2	Sodium nitrate..... Potassium chloride.. Acid phosphate.....	125 100 375	3.11	552.65	56.3
3	Sodium nitrate..... Acid phosphate.....	125 375	3.51	580.75	54.0
4	Sodium nitrate..... Potassium chloride..	125 100	2.74	495.90	61.3
5	Check.............		2.06	310.55	51.1
6	Potassium chloride.. Acid phosphate.....	100 375	2.06	296.45	58.3
7	Sodium nitrate..... Potassium chloride.. Acid phosphate.....	125 100 375	3.32	471.40	67.6
8	Sodium nitrate..... Acid phosphate.....	125 375	3.12	637.40	69.0
9	Sodium nitrate..... Potassium chloride..	125 100	2.61	374.50	61.6
10	Check.............		1.91	258.75	58.8

Lack of cross-pollination may be the explanation of this low yield. The results would be more nearly convincing if the yields were larger. Generally the plats making the largest growth yielded the most. Certainly applications of nitrogen were very beneficial. There is a slight suggestion that phosphorus also was beneficial. Yet, since plats receiving complete fertilizer yielded less than did the plats receiving nitrogen and phosphorus, the evidence in favor of a benefit from the application of phosphorus is but slightly stronger than that in favor of an injurious effect from application of potassium. It seems probable that only nitrogen was beneficial. In each of the years 1915 to 1919 the trees in the check plats had a slightly lower estimated percentage of a full bloom than had the plats which received applications of nitrogen; but the difference was so small as to be unimportant. In the year 1918 the percentage of flowers setting fruit seemed to be a little the larger on trees in plats receiving applications of nitrogen.

In this orchard where, probably due to imperfect pollination, the use of nitrogen did not cause the trees to bear very heavy crops, application of nitrogen caused a very decided increase in the size of the fruit. A smaller percentage of the fruit was well colored in the plats receiving nitrogen than in the check plats or the plat receiving only potassium and phosphorus; but the percentage of well-colored fruit in the plats receiving potassium and phosphorus was no larger than that in the check plats.

The same workers, using Rome Beauty trees planted when the experiment began in 1911 and Grimes Golden, Ben Davis, and York Imperial trees nine years old when the experiment began in 1913 — both orchards being at Sleepy Creek in a soil classified as Holston silt loam, a soil more fertile than that of the Reynolds orchard — seemed to find growth and fruitfulness slightly increased by use of nitrogen in cultivated orchards. The results were not entirely consistent, however, and the differences were not generally large enough to justify the use of nitrogen. Potassium and phosphorus seemed almost certainly not to have influenced growth or fruitfulness.

In a young bearing orchard in a poor soil in which the trees had a weak appearance and dropped their leaves early, applications of nitrogen caused a very striking increase in growth, although the orchard was cultivated.

In Arkansas. Cooper (591) reports that in very open gravelly soils in the Ozark region, Arkansas, apple trees showed marked response to applications of nitrogen; a much larger percentage of the flowers setting fruit. While he does not say, it is probable that his orchards were cultivated.

Summary. To review briefly; with the apple in cultivated orchards no conclusive results have been obtained indicating any response from the application of fertilizers to apple trees growing in a clay soil that is not particularly low in available forms of any element. Unquestionably, for apple trees to show response to applications of an element, the soil must have a lower supply of that element than it must have for some other crops to show response. In poor sandy or gravelly soils marked response to applications of nitrogen has been obtained even in orchards under the cultivation and cover-crop system. When the trees make weak growth and are unfruitful because the soil is compact or wet and poorly aerated, application of nitrogen seems not to cause improvement. Much greater response to applications of nitrogen has been obtained when the trees have been growing in sod. In fact, it seems probable that in any soil trees in sod will respond in yield and growth to applications of nitrogen, and that, with some varieties at least, early spring applications of nitrogen are necessary if a satisfactory percentage of the flowers are to set fruit. Occasionally an orchard is in soil so low in nitrogen that even in a cultivated orchard such early applications of available nitrogen may be necessary for the setting of fruit and for satisfactory growth. When a sod orchard is ploughed, nitrogen becomes available rather rapidly and the trees respond in growth during the season immediately following the ploughing. However, unless the ploughing and pulverizing of the soil is done in the fall or very early spring, a small early application of available nitrogen may be desirable for the setting of fruit.

In sod orchards, or in cultivated orchards in soil very low in nitrates, applications of nitrogen increase fruit-bud formation. Further, the evidence indicates that the apple is not readily thrown into excessive wood growth with reduced fruitfulness following applications of nitrogen. Even when the growth has been very greatly increased, fruitfulness also has generally been increased; though the color of the fruit was often reduced. Thus, if with the apple there is for greatest fruitfulness a necessary balance between nitrogen and carbohydrates, it is not easy under prevailing conditions to disturb that balance and reduce fruitfulness by applying nitrogen. Perhaps if other factors, such as the water supply, that assist in determining growth were at the optimum at all times during the summer, there would be more danger that application of nitrogen to mature apple trees would throw them out of fruiting and into excessive vegetative growth. In exceptionally well-aerated soils in some climates, use of large quantities of nitrogen may cause a delay of a year or two in the beginning of bearing with young trees; but such a delay will generally be profitable because of the larger crops later.

While the evidence is not conclusive, the apple tree seems to show no response to applications of lime in soils in which legumes and some other crops will show marked response.

Applications of phosphorus, even in soils very low in that element, do not seem to have caused the slightest response in growth or fruitfulness of apple trees.

The evidence as to response of apple trees to applications of potassium is conflicting. There is little doubt that the soil may contain so little potassium that apple trees will show marked response to its application. Some results where the experimental error was exceedingly large suggest that the trees may show response to applications even in soils fairly well supplied with potassium. If results reported by Brooks (578) and Shaw

(705) in Massachusetts were beyond question, the conclusion would be inevitable that, even in soils rather well supplied with all elements, response to applications of potassium may be very great. However, a survey of the different apple-orchard experiments brings out forcibly the fact that in any experiment with only one check even very large differences may be due to other influences than the treatments given. Further, in all other experiments in American soils, even when much lower in mineral nutrients, there has been no such large response to applications of potassium. It seems almost certain that in that experiment much, if not all, of the large apparent response to applications of potassium was in reality a response to other soil differences, perhaps a difference in soil aeration. While in none of the experiments discussed has the experimental error been small enough to justify an unqualified conclusion that there was no response to applications of potassium, at least, the results indicate that in nearly all American orchard soils, if other conditions are satisfactory, very large crops can be obtained without the application of that element.

The Pear

There is little evidence of any kind concerning the response of pears to applications of fertilizers. In Pickering's mixed orchard at Millbrook, pears showed response similar to that shown by apples, though the results were not so nearly uniform. Reimer (656) seemed to find the yield of Winter Nelis pear trees twenty-nine years old increased about twenty-five per cent as a result of applications of five to ten pounds to the tree of sodium nitrate, ammonium sulphate, or calcium nitrate. The size of the fruit also was increased rather markedly. The soil, near Medford, Oregon, was rather low in nitrogen, and probably apple trees also would have responded to applications of that element. Further, there was only one check and the experimental error may have been nearly as large as the difference indicated.

Mr. A. Kikuchi, working in Japan, found a rather large increase in growth of Chojuro pear trees and in yield and size of fruit as a result of applications of fertilizer, particularly nitrogen and potassium. Under his conditions applications of potassium seemed to have the greatest effect on the size of the fruits, those on plats receiving potassium being nearly twice as large as those on plats receiving no potassium.

Since the fruiting of pear orchards is so greatly influenced by pear blight, it would seem probable that conclusive results as to the effect of fertilizers, except in the case of soils where the need is very great, could seldom be obtained. Observation in the experiment station orchard at

Ithaca, New York, indicates that the pear is injured more by sod than is the apple; and observation in orchards indicates that the pear tree is more liable than the apple tree to reach a condition where the flowers drop badly without setting. It does not seem impossible, then, that, even to a greater extent than with the apple, the pear might show increased percentage of flowers setting fruit in response to applications of sodium nitrate about a month before the blooms open. The great complication with the pear is the fact that increased growth of the tree is liable to result in greater injury from blight. It is doubtful if one would find it wise to maintain pear trees at the state of vigor that would favor greatest fruitfulness and it is doubtful if nitrogen should ever be applied except to sod orchards or to cultivated orchards in unusually poor soil. Even then the applications should probably be small, perhaps not more than one hundred and fifty or two hundred pounds of sodium nitrate to the acre; and it is probable that a readily available form like sodium nitrate should be used, so that nitrate nitrogen would largely disappear before mid-summer. The wood, in some climates at least, might then be ripe enough, by the time when weather conditions were most favorable to the development of blight, for the tree to be in less danger from that disease. It does not seem impossible that the best method of soil management in a humid section where blight is serious is to keep the orchard in sod and to apply sodium nitrate two or three weeks before the bloom with the purpose of causing a larger percentage of the blossoms to set fruit. This should encourage a healthy early growth, and yet the effect of the sod should be to check growth and encourage hardening of the wood before the most favorable weather for the development of blight would appear.

The Quince

Few or no experimental data concerning the response of the quince to fertilizers are available. It presents the same problem with blight that the pear presents; and a system of soil management like that suggested for pears might be desirable for the quince. Hartwell and Damon (618) present data suggesting that in an acid soil the quince will respond to applications of lime, even though in the same soil the apple, pear, peach, and cherry failed to respond to applications of that substance. Only a small number of trees were used, however, and no evidence is given as to the size of the probable error.

The Peach

The peach offers special difficulties in experimental work. The tree is attacked by many diseases; and so in some sections it is difficult to obtain an orchard in which the trees are near enough to uniformity in size and general condition to make dependable experimentation possible. Further, the fruit buds and important wood tissues are liable to be injured in winter, thus introducing a still greater source of error. On the other hand, in the sections protected from winter freezing, such as those around the Great Lakes, the peach tree is one of the most uniform of the fruit trees in its bearing habit. Its response to treatment is uniform and marked; it comes into bearing young and has a short bearing life. In actual fact, though less experimenting has been done with peaches than with apples, the results seem more conclusive.

Jenkins (634) performed some experiments primarily intended to test the effect of different amounts of potassium on the fruiting of peach trees; though one plot received one hundred and seventy pounds of cotton-seed meal (which bears nitrogen) to the acre. Peach Yellows and other sources of injury to the trees interfered with the results; and so, while the plat receiving cotton-seed meal and those receiving the largest quantities of potassium yielded the highest, there were no differences that could be considered greater than the experimental error involved.

McCue (666) reported the results of experiments with fertilizers for peach trees growing in a clay loam soil in Delaware. The orchard was cultivated and a cover-crop of oats was used. The trees were planted in the spring of 1908 and the total yield during 1912, 1913, and 1914 is shown in Table 40.

The striking results are from the use of nitrogen. In plat 23, where more than one thousand pounds to the acre of sodium nitrate was used, the yield was much larger than that in any other plat except 16, which also received very large quantities of sodium nitrate (more than six hundred pounds) and plat 11, which also received nitrogen. Unusually large applications of nitrogen not only failed to cause a vegetative growth unfavorable to fruiting, but instead very greatly increased fruitfulness as well as growth. Plat 19 gave contradictory results; but it was in a low part of the orchard where frost killed the blossoms. The use of phosphorus certainly was not beneficial; and, while there is a slight suggestion of benefit from application of potassium, on account of the variation in yield among the plats, the evidence is far from being convincing. Applications of potassium did not seem to influence the color of the fruit. Nitrogen reduced both size and color of the fruit and delayed ripening a week to ten days. Probably the reduction in size was due to the heavy crops and the reduction in color to shade from greatly increased foliage.

McCue (667) found that in Delaware, after two or three years of growth, a cover-crop of cowpeas would begin to furnish enough nitrogen

TABLE 40. THE INFLUENCE OF VARYING QUANTITIES OF NITROGEN, POTASSIUM, AND PHOSPHORUS ON THE YIELD TO THE ACRE OF PEACHES IN DELAWARE

PLAT	TREATMENT AND AMOUNTS APPLIED TO AN ACRE	TOTAL YIELD 1912, 1913, AND 1914 (baskets)
1	Potassium chloride (50 lbs. K_2O)	764.4
2	Check	842.5
3	Potassium chloride (100 lbs. K_2O)	1565.9
4	Acid phosphate (50 lbs. P_2O_5)	962.7
5	Check	503.7
6	Acid phosphate (100 lbs. P_2O_5)	824.5
7	Check	622.0
8	Potassium chloride (50 lbs. K_2O); acid phosphate (50 lbs. P_2O_5)	839.6
9	Sodium nitrate (50 lbs. N)	2210.7
10	Check	1028.2
11	Sodium nitrate (50 lbs. N); potassium chloride (50 lbs. K_2O)	2751.7
12	Sodium nitrate (50 lbs. N); acid phosphate (50 lbs. P_2O_5)	1481.9
13	Potassium chloride (100 lbs. K_2O); acid phosphate (50 lbs. P_2O_5)	925.0
14	Potassium chloride (50 lbs. K_2O); sodium nitrate (50 lbs. N); acid phosphate (50 lbs. P_2O_5)	990.6
15	Potassium chloride (50 lbs. K_2O); sodium nitrate (100 lbs. N); acid phosphate (50 lbs. P_2O_5)	2013.8
16	Sodium nitrate (100 lbs. N); potassium chloride (50 lbs. K_2O)	2952.8
17	Sodium nitrate (100 lbs. N); acid phosphate (50 lbs. P_2O_5)	2445.5
18	Check	815.0
19	Sodium nitrate (50 lbs. N); potassium chloride (100 lbs. K_2O); acid phosphate (50 lbs. P_2O_5)	247.8
20	Check	294.3
21	Sodium nitrate (50 lbs. N); potassium chloride (50 lbs. K_2O); acid phosphate (100 lbs. P_2O_5)	1577.7
22	Sodium nitrate (50 lbs. N); potassium chloride (150 lbs. K_2O); acid phosphate (50 lbs. P_2O_5)	2030.0
23	Sodium nitrate (150 lbs. N); potassium chloride (50 lbs. K_2O); acid phosphate (50 lbs. P_2O_5)	2706.1
24	Sodium nitrate (50 lbs. N); potassium chloride (50 lbs. K_2O); acid phosphate (150 lbs. P_2O_5)	1937.4

for the most desirable growth and fruitfulness. However, during the first few years of the orchard, application of nitrogen in addition to that supplied by the cowpeas was desirable.

Alderman (550) reported the results of fertilizer experiments with peach trees in West Virginia with a thin red shale loam soil that was very low in mineral nutrients and was appreciably acid. The work was begun in 1911, the trees being then seven years old. Results as to growth during four years are shown in Table 41.

The materials were used at the following rates: sodium nitrate, 200 pounds; acid phosphate, 335 pounds; potassium chloride, 135 pounds to the acre. In one plat the amount of potassium chloride was used at the rate of 270, and in one 395 pounds to the acre. Shoot growth was doubled by the use of nitrogen and leaf surface increased nearly fourfold.

TABLE 41. EFFECT OF FERTILIZERS ON THE TWIG GROWTH AND LEAF AREA OF PEACH TREES

	SHOOT GROWTH (inches)	LEAF AREA TO THE TREE (square feet)
Nitrogen and phosphorus	16.10	755.6
Nitrogen and potassium	14.47	734.4
Complete fertilizer	15.00	654.3
Potassium and phosphorus	8.16	212.6
Check	7.28	160.1
Complete fertilizer	14.40	845.0
Complete fertilizer, potassium doubled	15.59	986.7
Complete fertilizer, potassium trebled	15.00	670.0
Lime	7.84	320.8

Of particular interest is the effect of nitrogen on fruit-bud formation. Alderman attempted to indicate the fruit-bud formation in terms of percentage. Thus, 100 per cent would mean that practically all of the new growth contained two buds at each leaf or cluster of leaves. The results are shown in Table 42.

TABLE 42. EFFECT OF FERTILIZERS ON FRUIT-BUD FORMATION WITH THE PEACH

TREATMENT	1912 (per cent)	1913 (per cent)	1914 (per cent)	1915 (per cent)	Average (per cent)
Nitrate and Acid phosphate	85	100	100	37.5	80.6
Nitrate and potash	87	100	90	25.0	75.5
Complete	81	100	90	25.0	74.0
Check	42	60	50	80.0	58.0
Potash and acid phosphate	49	60	50	72.5	57.9
Complete	90	94	90	32.5	76.6
Complete with potash doubled	94	92	85	30.0	75.2
Complete with potash trebled	92	98	85	30.0	76.2
Lime	40	75	70	72.5	64.4

Except in 1915 there were much larger percentages of fruit buds on the trees receiving applications of nitrogen than on the others. When it is considered that the trees were much larger, it will be realized that very many more fruit buds were borne. The smaller percentage of buds in 1915 on trees receiving applications of nitrogen is explained by the fact that they bore extremely heavy crops in 1914.

The effect of the different nutrients on the yield of fruit is indicated in Table 43.

Since the treatments began in 1911 and the number of fruit buds and the bearing surfaces of the trees had been determined in previous years, the crop of 1911 was not measurably influenced by any treatment. Applica-

Table 43. Effect of Fertilizers on the Yield of Peaches in West Virginia

Treatment	1911 (lbs.)	1913 (lbs.)	1914 (lbs.)	Average (lbs.)	Average 1913 and 1914 (lbs.)
Nitrogen and acid phosphate	41.88	74.08	93.9	69.95	83.99
Nitrogen and potash	47.30	81.29	87.2	71.93	84.24
Complete	48.49	64.79	92.9	72.06	78.84
Check	46.81	51.32	50.3	49.48	50.81
Potash and acid phosphate	45.69	46.86	34.7	42.42	40.78
Complete	51.63	90.76	104.5	82.29	97.63
Complete with potash doubled	52.38	99.67	94.2	82.09	96.93
Complete with potash trebled	49.09	107.97	90.7	82.59	99.33
Lime	44.13	58.53	79.8	60.82	69.16

tion of potassium and phosphorus apparently has not influenced the yield, though application of nitrogen very strikingly increased it. It is interesting to note that the lime plat, while yielding less than those receiving nitrogen, yielded more than any other plat not receiving nitrogen. The results seem hardly significant, however, since the difference between its yield and that of the check is not greater than the difference between the yields of two plats receiving complete fertilizer. Certainly in this acid soil the use of lime has had little, if any, influence on yield of fruit. The effect of nitrogen on maturity was in agreement with the results of McCue, the nitrogen delaying maturity a week to ten days. Nitrogen had the effect of reducing the amount of red color in the fruit; but Alderman thinks that a part of this may be accounted for by the fact that the fruit from the nitrate plats was not so ripe when picked as that from the other plats. Of course, with the increased foliage much less sunlight reached the fruit of trees receiving nitrogen.

There was slight evidence that potassium increased the size of the fruit. When it was graded according to size, the average percentage that fell in the fancy and extra fancy grades was for plats receiving potassium 31.8, and for plats receiving no potassium 25.2. The size was slightly greater also in case of plats receiving nitrogen than in case of those receiving no nitrogen. One would expect the increased vigor due to the use of nitrogen to result in increased size of fruit. This does not seem always to be true, however. In some experiments in very poor gravelly soil in the Ozark region of Missouri, in dry sunny seasons, the use of nitrogen reduced the size of the peaches. This was true even when the trees receiving nitrogen were not bearing more fruits than the others. It was suggested in Chapter 8 that this might be explained by the greatly increased foliage on the nitrate plats.

In this soil Alderman did not observe any effect of nitrogen on the growth of trees the first year after they were planted. However, in very poor worn soils in the Ozark region very marked effects of nitrogen were observed in the year of planting; and, at the Cornell University Experiment Station, Elberta peach trees to which nitrogen was applied showed during the season in which they were planted a forty-five per cent increase in leaf surface as compared with the check; and the soil in which they grew, while low in nitrates, contained enough that apple trees would not respond to applications of nitrogen.

Crane (591a) has continued in West Virginia the experiment started by Alderman with Carman and Waddell, also an experiment with Carman and one with Elberta in another soil, a Dekalb shale loam low in fertility. It does not seem necessary to give any of his tables, since in all cases the application of nitrogen strikingly increased shoot growth and yield. Applications of nitrogen made about five or six weeks before the bloom did not cause a better yield than applications made during the blooming time; in fact, it seemed to cause less increase in yield. Applications of nitrogen made June 15th or July 15th caused less increase in yield, but apparently more increase in growth than was caused by applications at blooming time. While nitrogen caused a greater shoot growth it did not always cause a greater trunk growth. Unlike the apple, trunk diameter does not seem to be so closely correlated with total tree growth and fruitfulness with the peach. Perhaps the increased fruiting reduced trunk growth; or, since growth continues later with the peach than with the apple, it may be that the much larger leaf surface, by causing a large daily water deficit as summer transpiration became high, reduced growth in the trunk. The growing points of the shoots with their higher sap concentration may be able to obtain water when there is a deficit in other parts of the tree.

Trees receiving nitrogen had in some years a larger number of fruit buds relative to the number of nodes and in other years a smaller number. Probably the heavy crop in some years reduced the percentage of fruit buds formed. However, there were always more buds on the trees receiving nitrogen even when the percentage was smaller, there being so many more nodes.

The size of the fruit was not increased by the nitrogen; but, generally, on account of the heavier crops, it was slightly decreased. Nitrogen reduced the color of the fruit and delayed its ripening several days, the delay being greater with the heavier applications.

Larger percentages of the fruit buds were killed in winter on trees receiving nitrogen than on the others, the largest percentage being killed on trees receiving applications of nitrogen July 15th. However, on account of the longer shoot growth, there were in the spring more live buds to the shoot and more to the tree than on trees to which no nitrogen was applied. Perhaps enough for a crop of fruit were as resistant as any buds on the unfertilized trees. However, we have no convincing evidence that a large amount of nitrogen relative to carbohydrates in a tree may not tend slightly to reduce the resistance of all its tissue to freezing.

There was in West Virginia a considerable residual effect of applications of sodium nitrate, trees making more growth in the spring of the next year after the nitrogen was applied than was made by unfertilized trees.

In the experiment with Elberta trees the use of a leguminous cover-crop, soy beans or crimson clover, seemed to cause an increase in growth as great as that caused by the application of four pounds of sodium nitrate to the tree; but it did not cause any increase in yield. Crane thinks it possible that the cover-crop tended too greatly to deplete the water supply.

There is no strong evidence in any of Crane's experiments that application of potassium or phosphorus influenced in any way the growth or development of the tree or the fruit.

Blake (571) applied sodium nitrate at the rate of two hundred pounds to the acre to peach trees low in vigor, the application being made just as growth started in the spring. This seemed to increase the percentage of flowers setting fruit and to reduce the number of fruits to fall in the June drop. Since the bloom was a rather light one, however, the crop even on the trees receiving nitrate was not excessive and the fruit on these trees was considerably larger than that on the ones to which no nitrogen was applied. The total yield of the trees receiving nitrogen was nearly twice that of the checks.

In a poor gravelly soil in the Ozark region peach trees showed very much greater response in growth to application of nitrogen than was shown by apple trees in adjoining plats. In fact, while the response of peach trees represented the difference between a very small unsatisfactory growth and an exceptionally vigorous growth, that of apple trees was hardly measurable, if there was a response. The fact has been mentioned that in the Cornell Experiment Station orchard, in an open sandy soil low in nitrates, but well drained and well adapted to the growth of young peach trees, peach trees showed marked increase in growth as a result of applications of sodium nitrate; though apple trees following in the same plats with the same treatments did not show the slightest response to applications of nitrogen. The apple trees, both fertilized and unfertilized, made excellent growth, while the peach trees, receiving no applications of nitrogen, made only a medium growth, and the leaves were of a rather pale green color; the growth of the fertilized peach trees being exceptionally vigorous.

The evidence of all experiments reported indicates that for best growth and fruitfulness the peach tree requires a soil richer in nitrate nitrogen than is required by apple trees, and will show a response to applications of nitrogen in any soil in which common field crops will show response and probably in some soils in which for lack of phosphorus some field crops will not show response to applications of nitrogen. No experimental results have come to my attention in which peach trees have formed fewer fruit buds as a result of the vigorous growth caused by applications of nitrogen. Rather, application of nitrogen generally greatly increases fruit-bud formation, even extremely large applications having that effect. The limit as to amount of nitrogen that it is wise to apply to peach trees, then, is determined, not by the danger of throwing the trees into a vegetative condition unfavorable to fruiting, but rather by the increase in yield — either the immediate increase or the increase resulting later from increased growth — as compared with the cost of the use of nitrogen; and by the effect on the color and quality of the fruit; and the increased susceptibility to brown rot.

In humid sections in nearly all soils in which peach trees are grown to any extent they seem to make at least a small response to applications of nitrogen. However, in some soils of California, the supply of available nitrogen is so large that even peach trees do not seem to make any response to its application. In such rich soils in humid sections, the color and perhaps the quality of the peaches would probably be injured by its excessive growth. Perhaps in California the large amount of sunlight, with the resultant high carbohydrate supply and the check to growth caused by high transpiration, prevents such an effect. If rainfall is heavy and the nitrogen supply is such that trees make an exceptionally vigorous growth, young trees in the third season may drop the fruit worse than it is dropped by trees in lower vigor; but in spite of occasional dropping of the fruit such vigorous growth of young trees may be desirable; for, due to the great increase in size of the tree, the crop in the succeeding year may be more than enough to compensate for any fruit lost from a small tree in its first bearing year.

In all of the experiments so far discussed there was no response to applications of phosphorus; and if there was any response to applications of potassium that response was too small to be detected with certainty. However, Picket (684) has published some results that suggest a large indirect benefit to peach trees from the application of potassium in a soil low in humus, total nitrogen, and phosphorus, and rather high in potassium — a gray silt loam over compact clay. His results are only for the first crops that were borne during the fourth summer in the orchard. The increase in yield due to applications of potassium was small in soil under clean cultivation. However, the part of the orchard with which cowpeas were used as a cover-crop without fertilization yielded much less than did that having clean cultivation without fertilization; but trees in the part in which cowpeas were used as a cover-crop, but to which potassium or potassium and nitrogen were applied, yielded as much as trees with clean cultivation or a little more. Until the trees are older and the results are published in such a way that they can be critically examined with reference to soil variations in the field, it is not safe to draw conclusions. It is possible that soil variations may account for the difference. Even if there is in this orchard a marked response to applications of potassium, the results certainly are not typical of what might be expected in soils well adapted to the growth of peach trees. This is not such a soil. Picket says that apple trees in the same soil do not seem to respond to applications of potassium. It seems possible that the available potassium is leached into and adsorbed by the compact subsoil and that apple-tree roots will penetrate that subsoil better than will peach-tree roots. It is well known that apple trees will thrive in heavy wet soils much better than peach trees. Experimental evidence and experience in peach growing give convincing evidence that in very few American orchard soils can such striking results be expected from applications of potassium or phosphorus as often follow applications of nitrogen. Generally little or no response can be expected.

The peach tree seems very tolerant of acid and does not generally respond to applications of lime.

The Cherry

Very little experimenting has been done with fertilizer for cherries. Blake and Farley (572) report the results of an experiment with sour cherries in New Jersey. All the plats received equal parts of ground bone, potassium chloride, and acid phosphate at the rate of 500 pounds to the acre, two of the plats receiving an additional 150 pounds of sodium nitrate to the acre. The soil is described as a heavy moist loam containing some clay and fairly rich in nitrogen. The experiment, then, would be to determine whether or not in a soil reasonably rich in nitrogen and receiving some in the form of ground bone additional quantities would be profitable. While not enough trees were included in the plats, the evidence seems fairly conclusive that both yield and tree growth were rather markedly increased by this application of nitrogen.

Roberts (1123) found in Wisconsin that vigorous growth of sour cherry trees resulting from the use of nitrogen increased the hardiness of fruit buds by delaying their development. He reports a case where by use of vines and hulls from a pea cannery a man greatly increased the growth of the trees and also their productiveness. Later Roberts and Potter (702) reported results of an experiment in a silt loam soil of limestone origin. The use of nitrogen increased both yield and growth rather markedly, while potassium and phosphorus did not seem to cause any response as to growth or fruitfulness.

Collison (587) conducted an experiment with fertilizers for cherry trees (probably Montmorency) at Geneva, New York. The experiment began in 1913 and the results include the season of 1919. The soil, an Ontario loam, is rather well supplied with all elements. The trees were under cultivation, and were five and six years old at the beginning of the experiment. There is slight suggestion of benefit from potassium and phosphorus, but not enough to be at all conclusive. Nitrogen seemed certainly beneficial as to growth, but hardly enough as to fruitfulness to be profitable.

In the same soil, heavy clay, in which Lyon, Heinicke, and Wilson found apple trees in cultivation to make but slight response, or no response, to application of nitrogen, Montmorency cherry trees, also cultivated, made about fifty-five per cent more growth in plats receiving large applications of sodium nitrate than in unfertilized plats. And in the Cornell Experiment Station orchard, in a light sandy soil, Montmorency cherry trees made very striking response in growth and appearance of vigor to applications of nitrogen, though young apple trees in the same soil in abutting rows did not show the slightest response. The sour cherry tree seems to be like the peach tree in its response to applications of nitrogen. Little is known as to its response to a high or a low potassium or phosphorus supply, except that it does well without applications of phosphorus in soils in which corn will make only a very weak growth unless available phosphorus is applied.

I do not know of any experimental results as to fertilizer requirements of sweet cherry trees. Casual observation indicates that when the nitrate supply is low, certainly when it is as low as that under sod, the trees may make striking response to application of available nitrogen.

The Plum

There are so many species of plums in cultivation that it is not improbable that very different responses would be shown by the different species. There is very little evidence concerning the responses of any of these species. Dyer and Shrivell (597) seemed to find that omission of potassium from the fertilizer reduces the yield markedly in case of Victoria plums (*Prunus domestica*). Their results are not conclusive, and they give little information as to their soil or their experimental method. On the Cornell Experiment Station grounds trees of *Prunus domestica*, *Prunus insititia*, and *Prunus salicina* with tillage seem to show greater response to applications of nitrogen than apple trees show. Shropshire damson plums (*Prunus insititia*), in the soil, under the tillage and cover-crop system did not show appreciably increased growth due to applications of nitrogen in the heavy clay Dunkirk soil in which Lyon, Heinicke, and Wilson found little or no response by young apple trees; but trees growing in sod showed striking response to applications of nitrogen.

Citrus Trees

Kinman (647) reports interesting results with Citrus fruits in Porto Rico. He worked in soils that were low in all of the elements, and generally under conditions where root growth would be very shallow. The experiment involved the omission of different elements in different plats. In every case, the omission of any element reduced the yield, though the omission of nitrogen reduced the yield the most. When an element was omitted, the foliage was smaller and lighter in color, and the growth of the top and trunk was much slower than where a complete fertilizer was used. Check trees receiving no fertilizer were included at first, but their growth was so poor that all but one check were discontinued. No difference was observed in the effect of any treatment on color, quality, or flavor of the fruit.

The work of Young (741) agrees with that of Kinman in so far as potassium and phosphorus are concerned. Applications of these elements did not influence the composition or quality of the fruit. In fact, application of potassium or phosphorus to the soil did not increase the percentage of either in the fruit. Applications of nitrogen, however, caused the fruit to have a slightly lower sugar content, and a slightly coarser texture, with a little less juice. This difference could not have been due to delayed maturity; for when the fruit was exceptionally ripe the effect was still to be found. The fruits on all trees in plats receiving nitrogen showed a slightly increased percentage of nitrogen.

Collison (590) studied in Florida the fertilizer responses of Valencia orange trees, beginning with the year of planting, in a coarse, reddish, sandy soil, which, analyses indicated, was in fertility a little above the average Citrus soil in Florida. The purpose was to determine the effect of varying amounts of each element on the chemical composition of the soil and on the responses of the trees. The standard treatment was three applications a year of a mixture containing five per cent ammonia, six per cent phosphorous pentoxide, and eight per cent potassium oxide, supplied in ammonium sulphate, acid phosphate, and high-grade potassium sulphate. Multiples of the standard amount of all the elements were applied to some plats and multiples of some of the elements to others. The amount applied was increased from year to year until by the end of the ten years the standard amount was six pounds to the tree. No yield records are given, but only the records of trunk-diameter increase. Reducing the amount of each element to half that of the standard treatment did not seem to reduce growth. Growth was not reduced greatly with the unfertilized trees. Probably the injury from lack of fertilizer would have been greater if the trees had been large enough for the roots to be occupying all the soil and none growing into soil areas that had not been depleted of nutrients. Twice the standard amount caused considerable injury to the trees and four times the standard amount caused a rather large amount of injury. Excess quantities of nitrogen seemed more injurious than excess quantities of phosphorus or of potassium in potassium sulphate. On the other hand, nitrogen, when not used in excess, seemed to be the element causing the greatest growth increase; though the evidence is not very clear as to this point. Clean cultivation throughout the year caused the greatest growth of any cultural treatment and caused the water and nitrate-nitrogen supply to be the largest. The soil was acid except as it was influenced by the treatments; and in some of the plats it was very acid; but acidity seemed in no case to reduce growth. In fact some of the trees making the best growth were in plats having the most acid soil.

Vaile (719), working in irrigated Citrus orchards in California, seemed to find no response to applications of potassium or phosphorus, whether used alone or with nitrogen. There was large response to applications of nitrogen. In fact in some of the orchards profitable Citrus growing was not possible without the use of nitrogen-bearing fertilizer.

Apparently Citrus trees, like most other kinds of fruit trees, will not show large response to applications of potassium or phosphorus unless the supply in the soil is rather low. In response to nitrogen they surpass even peach trees. In southern California peach and other deciduous fruit trees are grown satisfactorily with little or no fertilizers in soils very similar to those in which Citrus trees for profitable culture require very large applications of nitrogen. In such sections Vaile (720) found that the yield of orange trees is increased by increasing the amount of nitrogen applied up to 350 pounds of actual nitrogen to the acre, four to perhaps ten times the amount that would be applied in deciduous orchards in humid sections. The most profitable amount to use on an acre was generally less than 300 pounds of actual nitrogen, the amount depending on the price of the fruit. Of course, nitrogen is being used longer in the year by Citrus trees than by deciduous trees. Above 350 pounds to the acre seemed to cause a decrease in yield. Naturally, since the use of sodium nitrate or even of other concentrated carriers of nitrogen that have been studied in citrus groves in arid sections tend to cause mottle leaf and other injury to the trees, even killing back in the case of sodium nitrate, better results are obtained if a considerable proportion of this large nitrogen supply is furnished in coarse organic material such as manure. He found that, when less than forty per cent of the nitrogen was supplied in bulky manures, the yield was but about eighty-nine per cent of that when sixty per cent or more of the nitrogen was in such material. However, in the most productive groves there was some mottle leaf where such large quantities of nitrogen was applied even in coarse organic material. Citrus trees seem more sensitive than most other fruit trees to the changes in the soil caused by the application of sodium nitrate in arid sections; and, since they require such large applications of nitrogen, the injurious condition develops much more rapidly in the soil than with other fruits. Since at least a part of the injury from the use of sodium nitrate is due to the accumulation of sodium, it would seem that the use of calcium nitrate or ammonium sulphate would be better than the use of sodium nitrate. I know of no studies with calcium nitrate; but ammonium sulphate according to Vaile seems to cause less mottle leaf than does the sodium nitrate. However, both ammonium sulphate and dried blood seem to cause more mottle leaf than does nitrogen supplied in coarse manures.

The Grape

One would expect the response of grapes to fertilizers to be influenced by the training systems necessarily adopted. The vine is annually pruned very severely; the possible leaf surface and the number of fruits and growing points being much reduced. This large root system as compared with the size of the top should enable the vine to obtain an adequate mineral nutrient supply from soils in which the concentration of mineral nutrients is lower than that which would be necessary if the size of the top were not annually reduced by pruning. However, differences in response by different species are probably more important in determining the ability of a plant to obtain an adequate supply of mineral nutrients from a given soil than is the amount of pruning annually given.

Hedrick and Gladwin (626) and Gladwin (609) have published the results of an experiment with American grapes, *Vitis Labrusca.* The significant part of this work was done in the Chautauqua grape belt, in a soil listed technically as a Dunkirk gravelly loam. It is very deep, porous, and subject to leaching. The vines were 18 years old at the beginning of the experiment. In their plats, where nitrogen was used it was at the rate of 100 pounds of sodium nitrate, and at the beginning 800 pounds of cottonseed meal, to the acre. Later dried blood at the rate of 400 pounds to the acre — except in 1910 when 560 pounds were applied — was substituted for the cottonseed meal. Acid phosphate was applied at the rate of 300 pounds to the acre, and potassium sulphate at the rate of 200 pounds. Air-slaked lime was used at the rate of 2000 pounds to the acre every third year. After 1909 the dried blood and sodium nitrate were not applied early in the spring with the other elements, but were applied in two portions, one shortly after growth started and the other about three weeks later. In late July or August of each year a non-leguminous cover-crop was sown. The following table gives the results as to yield:

TABLE 44. THE EFFECT OF FERTILIZERS ON THE YIELD OF GRAPES (*Vitis Labrusca*) IN NEW YORK

PLAT	TREATMENT	1909	YIELD EXPRESSED IN TONS		
			5 year av. 1909–13	5 year av. 1914–18	10 year av. 1909–18
1	Complete fertilizer; lime	4.48	3.51	2.72	3.11
2	Complete fertilizer	4.76	3.96	2.92	3.44
3	Nitrogen and phosphorus	5.17	3.83	2.57	3.20
4	Nitrogen and potassium	4.25	3.87	2.94	3.40
5	Phosphorus and potassium	3.41	3.39	2.53	2.96
6	Check	3.38	3.12	2.03	2.58
7	Complete fertilizer; lime	4.69	4.10	3.23	3.67
8	Complete fertilizer	4.66	4.02	3.42	3.72
9	Nitrogen and phosphorus	4.99	3.97	3.16	3.57
10	Nitrogen and potassium	4.79	4.18	3.46	4.02
11	Phosphorus and potassium	4.99	3.61	2.92	3.27

The yield in 1909 is given as suggesting what the relative fruitfulness of the plats would be if no fertilizer had been applied, it being doubtful if any but the nitrogen could have influenced the crop during the first year. Some of the plats may have yielded relatively high in 1909 because of a relatively low yield in 1908, but the figures suggest that plat 1, receiving complete fertilizer and lime, and possibly plats 4, 5, and 6, are, but for the fertilizers, rather weak, and plats 3 and 11 slightly above the average. Until 1912 beneficial results from the use of the fertilizers were not apparent. By the end of 1913 benefit from the nitrogen was evident, and by the end of 1918 potassium also seemed slightly beneficial.

The same number of fruiting canes were left for each vine each year; and the increased yield must have resulted largely from the production of better fruiting canes or from an increase in the size of the berries in the bunches. According to Hedrick and Gladwin, beginning in 1912, the clusters on vines receiving nitrogen were larger and more compact, and the berries were larger. And Gladwin says that the fruit on the plats receiving phosphorus and potassium only was better in the same particulars than that of the check plat.

Whether the effect of phosphorus and potassium on yield of fruit and size of bunch and berry resulted directly from the effect of these two elements on the bunches, or whether it was indirect, resulting from the effect of these two elements on the cover-crop, and therefore on the nitrogen supply, we cannot say. Phosphorus particularly increased the growth of the cover-crops. This would result in the maintenance of a larger nitrogen supply. Of course, there is the further possibility that the single check plat was not representative of the experimental area. Early in the experiment the fruit on the plats receiving nitrogen matured earlier than that on other plats, though later there was little or no difference as to time of ripening. The grape thus seems to be an exception to the rule for most crops, with which nitrogen delays ripening. Zacharewicz (742) found certain wine grapes of France to mature earlier if the vines were fertilized with nitrate.

In Gladwin's work the effect of the nitrogen on wood growth was, of course, to increase it. In fact wood growth was nearly in proportion to yield. In Table 45 the ten-year average yield is compared with the average weight of prunings from the time the pruning weights were first kept, in 1911, to 1918.

It will be seen that with few exceptions the greater yields are associated with greater pruning weights.

It is interesting to note that, although phosphorus increased the growth of the cover-crops, rye, barley, wheat, and cowhorn turnips, more than did any other element, it has not appreciably influenced the yield of grapes.

It would be interesting to know whether or not these cover-crops responded to applications of lime. Otherwise we cannot know whether or not the failure of the grapes to respond indicates that this fruit is tolerant of a condition in the soil that makes liming necessary for some crops.

TABLE 45. COMPARATIVE EFFECT OF FERTILIZERS ON YIELD AND ON WOOD GROWTH OF GRAPE VINES (*Vitis Labrusca*)

TREATMENT	PRUNINGS — POUNDS TO THE ACRE ANNUALLY 1911–18	AV. ANNUAL YIELD IN TONS TO THE ACRE 1909–18
Complete fertilizer; lime	995	3.11
Complete fertilizer	1159	3.44
Nitrogen and phosphorus	966	3.20
Nitrogen and potassium	1117	3.40
Phosphorus and potassium	877	2.96
Check	711	2.58
Complete fertilizer; lime	1241	3.67
Complete fertilizer	1302	3.72
Nitrogen and phosphorus	1163	3.57
Nitrogen and potassium	1254	4.02
Phosphorus and potassium	1006	3.27

The soil may not have been in that condition. Hartwell and Damon (618) obtained conflicting results with lime for the grape in an acid soil.

Collison (587) reports the results of another experiment with grapes in the same section in which Gladwin worked. The soil was so low in phosphorus that both winter vetch and rye used as cover-crops showed very marked response. The plants were set in the spring of 1913, and a small crop was borne in the season of 1915. Table 46 gives the yield from 1915 to 1919 inclusive.

The complete fertilizer seems to have improved the yield, but there was certainly no response to application of phosphorus; and yet it is in this element that the soil is low; and it is to this one that the cover-crops show marked response. This experience is in agreement with the work of Gladwin, and suggests that the grape is able to obtain a sufficient amount of phosphorus for maximum yield from a soil so low in available phosphorus that rye and vetch show marked response to applications of that element. Whether the grape plant requires less phosphorus than these other crops require or whether it can use phosphorus in a form that is not available to these crops, we cannot say. If the greater yield on the plats receiving complete fertilizer is due to the fertilizer, then it is not possible from the table to say whether the increase is due to the potassium or to the nitrogen or to both. Although the soil was low in calcium there was certainly no response to applications of lime. Marre (670) also found sodium nitrate very beneficial to yield and growth of grapes (*Vitis vinifera*), whether used alone, with manure, or with other elements. Phosphorus added to the nitrogen increased the beneficial results.

Hedrick and Gladwin published results of coöperative experiments

TABLE 46. EFFECT OF FERTILIZERS ON GRAPES (*Vitis Labrusca*) IN NEW YORK

TREATMENT	AVERAGE YIELD BY THE PLAT TO THE YEAR (pounds)	INCREASE OR DECREASE OVER NEAREST CHECK (pounds)
Series 1:		
2000 pounds rock phosphate	248	+ 22
4000 pounds rock phosphate	209	− 17
Check	226	
Complete fertilizer	276	+ 50
2000 pounds acid phosphate	217	− 6
2000 pounds acid phosphate and 8000 pounds limestone	252	+ 32
Check	220	
4000 pounds rock phosphate and 8000 pounds limestone	263	+ 43
8000 pounds limestone	280	+ 60
Series 2:		
2000 pounds rock phosphate	269	− 2
4000 pounds rock phosphate	211	− 60
Check	271	
Complete fertilizer	394	+123
2000 pounds acid phosphate	384	+ 27
2000 pounds acid phosphate, and 8000 pounds limestone	326	−117
Check	443	
4000 pounds rock phosphate and 8000 pounds limestone	397	− 46
8000 pounds limestone	261	−182

with a number of growers. There were no consistent gains from the use of fertilizers. It seems probable that some other influence was causing large variation in yield in different parts of these vineyards. Some of the vineyards were poorly drained, so that this probably constituted the limiting factor as to growth and yield.

Zacharewicz (742) studied the effect of sodium nitrate in a complete fertilizer for grapes (*Vitis vinifera*) in various soils of France, and always found very marked response in yield and growth. The fruit also had a higher sugar content. Some of his soils were very low in potassium and some in phosphorus. In all check plats receiving no fertilizer the yield was below that where these elements were used without nitrogen, but since there were no plats receiving one of these elements without the other, the experiment furnishes no evidence as to whether or not the grape may produce optimum crops when one or the other of these elements is present only in very small quantities.

Gooseberries and Currants

In the case of gooseberries and currants as grown in America, the value of the crop is so small that a large increase in yield would be required before fertilizers could be profitable. Fertilizer experiments with them seem desirable, however, because of the fundamental information that might be gained. Thus, their fruiting habits are not very different from those of tree fruits; yet, because of their smaller size and the larger number of individuals that can be grown on a small plat, experimental results with them should be more accurate; and, if there should be an element more important for fruit formation than others, as potassium was formerly thought to be, its peculiar importance could be more readily determined with these small plants than with larger and more variable trees. Probably on account of their small economic importance, very little experimental work has been done with them in America. Further, it is generally recognized that gooseberries should be grown on a retentive soil rich in humus; and such a soil will generally be well provided with the mineral nutrients.

Pickering (681) reports some rather interesting results of experiments done in England. These were with *Ribes Grossularia.* The plants were in the soil at Ridgmont, in which apples showed no response. The following table gives his results:

TABLE 47. RELATIVE YIELDS OF EUROPEAN GOOSEBERRIES WITH DIFFERENT APPLICATIONS OF FERTILIZERS

DATE	NO MANURE	ARTIFICIALS EQUAL TO MANURE		MANURE	
		12 tons	30 tons	12 tons	30 tons
First series:					
1897	100	114	110	116	117
1898	100	104	121	71	64
1899	100	50	52	88	75
1900	100	80	109	127	149
1901	100	107	144	260	252
1902	100	0	0	108	115
1904	100	91	161	197	267
1905	100	76	104	865	1452
1906	100	70	119	642	985
1907	100	68	155	923	1289
1908	100	113	350	1153	1920
1909	100	313	613	2370	4830
1911	100	326	652	1350	4220
Plants alive in 1911	23	45	58	83	83
Second series:					
1913	100	134	150	208	469
1915	100	65	110	304	690
1916	100	83	155	307	680
1917	100	66	146	439	1064
Weight of bushes 1916–17	100	92	124	210	696

Concerning the data for the last few years, where the yield of the manured plat ran as high as forty-eight times that of the plat receiving no fertilizer, it should be considered that many more plants had died in the unfertilized plats, yet no allowance is made for this. Thus the 100 is for the total yield of 23 plants, while the 4220 is for the total yield of 83 plants. This procedure is followed because the greater mortality in the unfertilized plat resulted from the soil condition. Even when the smaller number of plants in the check plat is considered, the increase in yield to the plant due to the manure is still very great.

During the first few years of the experiment, the manure plats yielded less than the unfertilized plats. At this time the manured plants were growing very rapidly.

These results are interesting both on account of the constantly increasing benefit from the fertilizer, particularly manure, and on account of the very marked superiority of manure over equal quantities of the elements applied in the mineral form. Pickering did some experiments to determine whether this marked benefit from the use of manure could be due largely to its effect on the water supply. Thus, he used instead of the manure amounts of chaff large enough to equal the amount of straw in the manure; and no such benefits were obtained. The test ran only five years, however; and the manure had not given large benefits at the end of that time. These results do not exclude the possibility that the benefit from the manure was partly due to its effect on the water-holding capacity of the soil; though it seems probable that the gooseberry is benefited by having some element in an organic form.

Pickering conducted an experiment later to determine for this soil which elements were responsible for the increased yield. The plan was to omit from the fertilizer one of the essential elements in the different plats. The following table gives his results:

TABLE 48. SHOWING EFFECT OF OMITTING ONE ELEMENT ON THE YIELD OF EUROPEAN GOOSEBERRIES

TREATMENT	RELATIVE VALUES
No manure	100
Complete artificials	203
Artificials without nitrate	219
Artificials without potash	198
Artificials without phosphate	297

From this table it seems that omitting nitrogen or potassium did not influence the yield, and that omitting phosphorus actually increased it. The only conclusion to be drawn, then, is either that the fertilizer did not affect the yield or that the plats receiving complete fertilizer had their yields reduced by some other influence than the fertilizer; for if the fertilizer has been beneficial the omission of some element should have reduced the yield. Evidently these plats tell nothing as to the element which has been responsible for the increased yield.

Dyer and Shrivell (597) obtained markedly reduced yields when potassium was omitted from the fertilizer. This was true in three series where manure and phosphorus were used with and without potassium; though the manure furnished considerable amounts of potassium. The response of gooseberries to applications of potassium was larger than the response of potatoes and of most other crops on the same soil. It seems possible that the gooseberry may show a peculiar response to this element. These authors found in the same soil no such significant response of black and red currants to applications of potassium.

Pickering's experiments with red currants were not carried through as long a period, so there was not the opportunity for the cumulative effect that showed in the case of gooseberries; but for a five-year period the same tendency was observed, the greater benefit being caused by manure, and the larger quantities giving the best results.

As to Pickering's results at Ridgmont, it is interesting that both gooseberries and currants have responded to applications of fertilizers, particularly manure, in this soil in which apples showed no response. Of course, the same difference in response might not be observed in a soil better adapted to apple growing. It is possible that some other unfavorable condition than infertility so depressed the yield of apples that the trees were not able to make use of large quantities of fertilizers. The gooseberries responded even more markedly than onions and potatoes to applications of fertilizers in this soil. Of course, with annual crops there was not the cumulative effect resulting with gooseberries from the annual increase in growth and, therefore, in bearing surface.

At the Cornell University (583) fertilizer experiments with Downing gooseberries (probably a cross between *Ribes hirtellum* and *Ribes Grossularia*) and Fay currants (*Ribes sativum*) were begun in the spring of 1914, the bushes being planted in the autumn of 1913 on a rather heavy clay loam soil in which both species make rather slow growth. In the spring of 1914 the mineral elements were applied at the following rates: sodium nitrate, 200 pounds; acid phosphate, 14 per cent phosphoric pentoxide, 400 pounds; and potassium chloride, 100 pounds, to the acre. In 1915, 250, 450, and 200 pounds respectively were applied, and in 1916, 400, 900, and 200 pounds. These last rates have been used since 1916, except that in 1917 and 1918 no potassium could be applied. Manure and tankage, or dried blood, were used at such strengths that the estimated amounts of these elements were the same as with the mineral fertilizers, except that in case of tankage an excess of phosphorus was used in order to obtain enough nitrogen. The fertilizer was applied along the row near the plants, and was applied just before growth was starting. In Table 49 are shown the yields beginning with the first crop, 1915. On account of war conditions it was not possible to pick all of the 1917 crop.

TABLE 49. THE EFFECT OF FERTILIZERS ON THE YIELD OF CURRANTS AND GOOSEBERRIES

TREATMENT	1915 (lbs.)	1916 (lbs.)	1918 (lbs.)	1919 (lbs.)	1920 (lbs.)	1922 (lbs.)	TOTAL (lbs.)
Currants	25 plants to the row		15 plants to the row				
Manure	1.30	7.80	14.75	1.50	38.37	47.5	111.22
Manure	1.95	3.90	13.56	2.50	38.45	63.9	124.26
Tankage and KCl	2.60	5.20	20.88	3.00	40.67	62.6	134.95
Tankage and KCl	.98	3.90	13.88	2.50	37.78	81.6	140.64
NPK	1.30	3.25	27.81	4.00	51.68	62.0	150.04
NPK	2.60	2.60	25.69	3.50	53.24	101.2	188.83
Check	1.30	9.75	26.69	4.50	49.72	73.9	165.86
Check	1.70	11.05	28.75	3.50	51.40	70.1	166.50
N	1.30	11.05	27.31	3.75	49.01	97.7	190.12
N	1.30	10.40	26.13	2.25	40.17	91.8	172.05
P	1.30	6.83	26.75	4.00	48.36	69.0	156.24
P	.98	9.75	22.81	6.00	49.98	66.2	155.72
Check	2.60	7.48	22.56	6.75	53.60	64.0	156.96
Check	2.28	9.10	22.88	5.50	59.99	82.7	182.45
KCl	3.90	6.50	17.44	2.25	41.00	45.0	116.09
KCl	2.60	15.60	21.94	4.00	65.87	90.8	200.81
Gooseberries	10 plants to the row						
Manure	1.50	31.01	31.31	37.00	112.60	141.0	354.42
Manure	1.50	33.75	28.00	29.50	114.70	131.3	338.75
Tankage and KCl	4.50	34.13	28.25	24.25	76.20	162.3	329.63
Tankage and KCl	6.00	29.63	16.75	23.75	63.00	129.2	268.33
Check	6.00	21.50	19.38	12.00	56.00	53.3	168.18
Check	5.25	14.25	18.25	10.06	50.55	46.8	145.16
NPK	12.00	27.00	18.44	11.75	85.25	79.3	233.30
NPK	13.50	27.00	18.25	15.00	65.15	71.7	210.60
N	10.00	13.50	12.94	11.00	56.75	57.7	161.89
N	7.50	28.51	16.06	11.50	67.85	70.5	201.92
Check	3.75	8.63	9.56	12.81	66.25	44.6	136.04
Check	4.00	10.88	8.63	9.50	55.05	37.6	125.06
P	1.50	11.25	11.75	10.50	61.50	27.8	124.30
P	2.25	10.50	13.88	10.75	57.70	17.9	112.98
KCl	9.00	19.50	15.56	19.00	74.85	76.8	214.21
KCl	9.00	18.00	5.75	10.50	63.45	53.6	160.30

It will be seen that with the currants there is no suggestion of benefit from any of the fertilizer treatments. The soil, however, was not the most desirable for the currant and the "leaf spot" disease was not well controlled; and so it is still possible that with better soil aeration and better control of the "leaf spot" there might have been some response to applications of mineral nutrients.

With the gooseberries, however, there was rather marked benefit from some treatments. Thus, nitrogen alone seems to have benefited slightly, complete fertilizer very appreciably, whether the nitrogen was carried by sodium nitrate or by tankage; and manure caused a marked increase in yield. This greater benefit from manure is in harmony with the results of Pickering and of Dyer and Shrivell with European gooseberries. In the first fruiting year, however, nitrogen in sodium nitrate was more beneficial than was nitrogen in manure or tankage. Probably not enough nitrogen was available in the manure or the tankage, and the better growth resulted from the immediately available sodium nitrate during 1914, the first year in the planting. The plats receiving manure and tankage were ahead by the time of the second crop — the third year of the planting. Except in the first two years and until the last year the plants in the manure plat yielded more than the plants in the tankage plats and were much more vigorous in appearance. In 1920 dried blood was substituted for tankage — phosphorus then being applied in acid phosphate. The plants soon showed the benefit of the change to this more available form of organic nitrogen and in 1922 yielded as much as the manure plats or slightly more They became as large and perhaps even more vigorous in appearance. This result suggests that Pickering's view was correct; that the greater benefit from manure as compared with that from inorganic form of nitrogen is due to the fact that it supplies nitrogen in organic combination. This better response to nitrogen in organic combination we have not found with other fruits. There is a strong suggestion, at least, that the use of potassium has appreciably increased the yield. Thus, the complete fertilizer plat yielded more than that receiving nitrogen alone and the potassium plat more than adjacent plats not receiving potassium. However, this potassium plat had a tile drain running but three feet from one of the two rows — the highest yielding one — and it is possible that much of the increased yield and growth was due to better drainage. The plats receiving potassium held their leaves later and looked healthier than adjacent plants that did not receive potassium applications.

There is certainly no response to the use of phosphorus, and yet it was to this element that the cover-crops, oats and rape, showed the only marked response. Most interesting results in the same soil were obtained with maize. In the fall of 1917 a part of each row of gooseberries and currants was removed. The plants were weighed, in order to see if any element had influenced their growth. In 1920 maize was planted in the rows from which these plants had been removed. It was thinned until there were left three stalks in each hill. These were fertilized when the largest were about ten inches high. At that time the residual effect of the phosphorus applied in 1915–17 inclusive was very marked. After the first frost the maize was weighed, ears and stalk together where there were ears. The following table gives the results:

TABLE 50. THE EFFECT OF FERTILIZERS ON MAIZE IN A SOIL IN WHICH GOOSEBERRIES AND CURRANTS SHOWED NO RESPONSE TO APPLICATIONS OF PHOSPHORUS

TREATMENT	NO. PLANTS	AV. WEIGHT (lbs.)
Check	238	.16
No phosphorus	472	.16
Phosphorus alone	140	.68
Complete fertilizer	350	.69
Complete fertilizer, organic nitrogen	84	.86

The response to phosphorus is very great, 325 per cent. In fact this soil, though containing a rather large supply of total phosphorus, is so low in available phosphorus that maize will not form ears unless phosphorus is applied; and yet neither gooseberries nor currants will show a measurable response in yield or growth to its application. Either gooseberries and currants can use phosphorus in forms not available to maize, or they do not need as much of that element in the soil.

Hartwell and Damon (618) seemed to find rather marked benefit to currants and possibly some to gooseberries from the use of lime in an acid soil in Rhode Island, although with most fruit crops there was no benefit from the use of lime in that soil.

Raspberries and Blackberries

With raspberries and blackberries a large number of individuals grow in a small area and for that reason the experimental error should be smaller than with tree fruits. In actual fact, however, the experimental error seems rather large. The canes are killed to varying extents in winter; and both fruits are extremely responsive to slight differences in the physical condition of the soil. As to fertilizers, the practice, in most sections at least, is to use large quantities of manure; and sometimes mineral elements are used. This practice may result to some extent from the fact that these fruits are grown by market gardeners who for most of the vegetable crops must keep the soil very fertile. They would naturally be inclined to do that with their small fruits also, even though they might have no conclusive evidence that maintaining such high fertility is profitable. Experience indicates very strongly that it is desirable to have the soil extremely rich in humus at the time the planting is started. The young plants will reach bearing size much more quickly. As to whether or not the older plantings will justify maintaining the soil at such high fertility, we cannot say. Pickering (681) published results that suggest rather marked response to manure, the larger quantities (thirty tons) having given much the better results. There was some indication of response to the mineral fertilizers, but not so great as to manure. He used English varieties, probably of *Rubus idœus.*

Dyer and Shrivell (597), with English varieties in their poor soils, low in all essential elements, obtained better results with 12.5 tons of manure to the acre than with complete fertilizers containing more of each element. Twenty-five tons of manure did not cause better yields than were caused by 12.5 tons.

Jordan (638) published results of some fertilizer experiments with American red raspberries. There were no unfertilized plats to be used as checks, however. There was one plat receiving 20 tons of manure to the acre; another 500 pounds to the acre of a fertilizer containing 4.5 per cent nitrogen, 7.7 per cent phosphoric acid, and 13.3 per cent potash; another receiving 500 pounds of this fertilizer with additional quantities of potassium and phosphorus; and another receiving the same complete fertilizer with additional quantities of sodium nitrate at the rate of 200 pounds to the acre. No increase in yield resulted from the additional potassium and phosphorus, and plat 2, receiving the rather small quantity of complete fertilizer, yielded slightly better than the manure plat. Without checks we have no way of knowing that any of the plats yielded better than they would have if no fertilizer had been applied.

At Cornell University (583) some experiments were conducted to test the effect of fertilizers on cane fruits in the soil mentioned under the discussion of gooseberries and currants. In this soil, which is not satisfactory for these fruits, there was no indication of response in growth of any cane fruit to applications of either potassium or phosphorus without nitrogen. However, the variation was too great for one to say positively that no response resulted. The blackberries showed no response to applications of nitrogen. In growth Plum Farmer black raspberries showed some response but not as much as did Cuthbert red raspberry. There was with black raspberries no response, as to yield, that could be measured under the conditions of the experiment.

The effect of the nitrogen on the yield of red raspberries was not as marked as the effect on cane growth. In rows where as a result of the use of nitrogen there was very marked increase in cane growth, the yield was but slightly increased if at all. In Table 51 is given the yield, cane growth and yield to the cane in rows of about one one-hundredth of an acre each.

TABLE 51. EFFECT OF NITROGEN ON THE GROWTH AND FRUITFULNESS OF CUTHBERT RED RASPBERRIES

TREATMENT	YIELD IN OUNCES				AV. CANE HEIGHT (inches)				NUMBER OF CANES				OUNCES OF FRUIT TO THE CANE			
	1918	1919	1920	1921	1917	1918	1919	1920	1917	1918	1919	1920	1918	1919	1920	1921
Check	524	459	259	357	50.7	45.0	44.4	49.0	143	168	290	276	3.66	2.73	0.89	1.29
Check	381	584	445	450	47.0	44.5	43.1	55.0	130	242	430	341	2.93	2.41	1.04	1.32
Sodium-nitrate	607	618	438	595	54.3	46.7	44.8	63.0	209	252	477	491	2.90	2.45	0.92	1.21
	713	518	377	726	53.7	47.8	45.8	68.0	295	261	455	432	2.42	1.98	0.81	1.68
Check	662	512	419	432	52.7	49.6	41.8	51.0	256	228	425	344	2.59	2.25	0.96	1.23
Check	483	282	297	384	47.0	47.9	40.2	52.0	210	172	311	296	2.30	1.64	0.96	1.29
Dried blood	375	344	217	496	42.7	47.5	39.0	56.0	125	149	401	378	3.00	2.32	0.54	1.31
	582	442	228	560	47.3	48.2	39.2	58.0	252	212	445	399	2.31	2.09	0.51	1.43

The figures given for average cane length are misleading, because rather small suckers that grew late in the season are included, and there were many more of these in the rows to which nitrogen was applied than in the check rows. There were many more tall canes in the fertilized rows than in the check rows. The increased growth due to application of nitrogen is better shown in the column for the number of canes to the row. While nitrogen increased both yield and cane growth, the increased vigor of the canes did not cause proportionately increased yield, except in 1921. In the plats receiving nitrogen the highest yield to the cane was lower than in the check plats. It seems, however, that the reason for this reduction in fruitfulness of the individual cane is because of the crowding and shade due to the excessive number of canes in the row. Cuthbert, the variety used, is one that sends up suckers very readily; and in fertile soil the row tends to become too thick. If a variety that does not tend to sucker so readily had been used, it is possible that greater benefit from application of nitrogen might have been derived. It is also possible that if many of the suckers had been pulled out while they were small, increased cane length following the application of nitrogen might have brought increased cane yield. In 1920 the weather was unfavorable for excessively late cane growth; and so in 1921 the rows to which nitrogen was applied yielded considerably more than the check rows. In a light sandy soil at Webster, New York, with an old planting that had not been heavily fertilized, no fertilizer applications measurably increased the yield in a planting that seemed rather uniform.

Blackberries seem more easily injured by excess of sodium nitrate or ammonium sulphate than are other fruits except the strawberry. Thus, at Cornell University in the spring of 1922, when the sodium nitrate applied was not soon leached to deeper levels in the soil, blackberries were so injured that the canes of the previous season were killed and any but very weak new growth was prevented by an amount of nitrogen that was only slightly injurious to raspberries and was uninjurious to gooseberries, currants, and apples. As large an amount of nitrogen applied in dried blood was not injurious, but was not beneficial.

There were plats receiving applications of potassium and plats receiving applications of phosphorus; each element with and without the other and nitrogen. There was no indication of a response. Yet we have seen that with maize in the same soil the increase in growth due to the use of phosphorus was 325 per cent. Evidently raspberries and probably blackberries, like gooseberries and currants, either make smaller demands for phosphorus or can use it in a form that is not available for maize.

As to fertilizers, it seems that the best plan of management of a planting of cane fruits is, when the plants are set, to have the soil rich in humus, either through previous applications of manure or through ploughing under of green crops, and to apply little fertilizer afterward except that, with red raspberries, if the supply of available nitrogen becomes so low that cane growth is very weak, early spring applications of about thirty to fifty pounds to the acre of available nitrogen in organic or inorganic form may be desirable in order to obtain stronger canes that will fruit better unless they are left too thick in the row.

The Strawberry

Experimenting with the strawberry is very complicated and difficult. The plants themselves show the most marked variation as a result of slight differences in the physical condition of the soil, such as drainage, and are very susceptible to the toxic effects of some of the elements. One must be careful, indeed, in applying either sodium nitrate, ammonium sulphate, or potassium chloride closely around the plant, or one may kill it. Of course, if some of the plants in the row are killed, the yield will be affected even though a solid row may be formed late in the summer. (Incidentally one may say that it is always inadvisable to get any of these substances or potassium sulphate on the foliage of the plants unless the material is dissolved in water.) Then, too, plants differ so as to runner formation. With some varieties, such as Senator Dunlap, so many plants are formed that if the soil is especially fertile they may be so thick as to reduce fruitfulness; while with others, like Haverland or Bubach, few runners are formed but the plants fruit very heavily. Naturally with such varieties, when grown in the matted row system, anything that increases runner formation will tend to increase the yield. Thus, results one might obtain, with nitrogen-bearing fertilizers at least, using a variety of this latter type, might not necessarily be applicable to varieties of the former type.

Pickering (681) published results of experiments with strawberries, using the same treatments that were given to apples, gooseberries, and currants in the Ridgmont soil. There was no response to increasing amounts of fertilizers, and in fact in one series where no fertilizer was used the average result was as good as with large quantities of either inorganic fertilizers or manure. Bailey (556) has published results of a considerable number of experiments in the strawberry district in Oswego, New York. The soils experimented upon were generally gravelly or sandy, and probably somewhat low in all of the three important elements. The fertilizer was applied about the time of the first cultivation after the plants were set. Profitable returns seemed to follow the use of either potassium or phosphorus; and in a few plats application of manure seemed to increase the yield; though sodium nitrate generally influenced the yield but slightly if at all. Generally not enough checks were used; and it is not impossible that all of the differences in yield were such as would have been observed if no treatment had been given. However, while the evidence is hardly conclusive it suggests rather strongly that applications of phosphorus and sometimes of potassium were beneficial in these soils. Close, Ballard, and White (585) seemed to find that strawy manure used as a mulch reduced the yield.

In some experiments (582) with the Aroma strawberry, a prolific plant maker, at Sarcoxie, Missouri, in soil extremely low in nitrogen and low also in potassium and phosphorus, but not low enough in potassium or phosphorus for weeds to show appreciable response to applications of either, there was a strong suggestion that the strawberries responded to applications of phosphorus. In fact, in all series but one where acid phosphate was applied either the season that the plants were set or very early in the spring before fruiting, there was a little better yield on the plats receiving that nutrient. The experimental error in this work was certainly large, however; and in few cases were there enough checks used; and so the evidence can be considered as only suggestive.

In the soil at Cornell University in which gooseberries, currants, blackberries, raspberries, and apple trees showed no response, but in which oats, rape, and corn showed marked response to applications of phosphorus, strawberries showed nearly as great response as was shown by the oats and corn. It seems probable, therefore, that strawberries may show a response to applications of phosphorus in any soil in which corn or oats show such response.

While the evidence in the Missouri experiment concerning phosphorus was not conclusive, that concerning injurious results from the use of nitrogen was beyond question. Wherever the nitrogen was applied, in the spring before fruiting — or in the previous summer in a form that would remain in the soil until the spring before fruiting — marked injury was done. One feature, however, reduces the value of these results for general application. In the Sarcoxie district the berries are grown in a matted row, and the soil is so infertile that the weed growth in the row is very weak. For that reason, and also because under their conditions it would not be profitable, the weeds were not removed in the spring. In some soils the effect of the nitrogen applied in the spring was markedly to increase the weed growth, and thus to injure the plants. This injury would not result in a planting from which weeds are removed in the spring before fruiting. It is interesting that in a soil too low in nitrates for any but a very weak growth of weeds, strawberries would bear good crops without application of nitrogen. In plantings in soil where there was no weed growth among the plants, there was still the injurious effect of nitrogen applied in the spring before fruiting. The tendency was to encourage runner formation and reduce the amount of fruits. The Aroma variety, however, is not only a prolific plant maker, but fruits lightly and even during the fruiting season is easily stimulated to form runners instead of bloom stems. It is possible that if a variety had been used that sets very many fruits and is not easily forced into vegetative growth, application of nitrogen would have been profitable through its increasing the size of the fruit. While nitrogen applied to the one-year-old bed in the spring in the form of sodium nitrate markedly increased runner formation, it did not seem to have that effect when applied shortly after the plants were set the spring before; the effect of nitrate of soda applied shortly after planting time was not noticeable in any way. Probably the nitrate-nitrogen supply is low in the soil under a matted row in the spring, and considerably higher in the well-cultivated soil in early summer after the plants have been set! In New York, working in a light sandy soil at Webster, and a gravelly soil of the Hudson River section at Marlborough, I have not been able to find any increase in yield of strawberries as a result of applications of any element. With the varieties William Belt and Glen Mary, sodium nitrate or manure applied in the spring is certainly not as injurious as it was at Sarcoxie, Missouri, with Aroma; though application of neither substance measurably increased the yield. Where a straw mulch was used instead of the manure mulch, the plants at picking time were yellow, and did not seem to be doing as well; but they yielded as much.

Brown (579) did some experiments with strawberries in the upper Hood River Valley in Oregon. The rainfall there is not large, and there is less danger of excessive plant growth early in the growing season than in a more humid climate. Nitrogen, therefore, could be more safely used. The variety used was Clark's Seedling, one that bears sparingly. The practice in that section is to harvest a number of crops, sometimes five or six, before a bed is ploughed up. This experiment began when the plants had been growing one year and the bed was ready to bear its first crop and ran until the third crop was harvested. Table 52 gives his results.

TABLE 52. THE EFFECT OF FERTILIZERS ON THE YIELD OF STRAWBERRIES IN OREGON

PLAT	POUNDS APPLIED TO 10,000 PLANTS	TIME APPLIED		YIELD IN CRATES BY 10,000 PLANTS							
				Test No. 1				Test No. 2			
		Early spring	At blooming time	1916	1917	1918	Ave.	1916	1917	1918	Ave.
1	Sodium nitrate	220	..	257	230	110	199	302	148	165	203
2	Sodium nitrate	..	220	356	306	133	265	..	..	..	..
3	Sodium nitrate	110	110	441	237	154	277	257	189	175	207
4	Sodium nitrate	440	..	..	..	..	..	327	181	225	244
5	Sodium nitrate	220	220	448	257	138	281	349	192	209	250
6	Check	..	..	373	167	151	230	257	162	146	188
7	Sodium nitrate Superphosphate Potassium sulphate	220 470 125	..	384	208	154	248	293	171	151	205
8	Superphosphate Potassium sulphate	470 125	..	467	159	123	249	239	156	118	171
9	Sodium nitrate Potassium sulphate	220 125	..	438	197	148	261	289	173	135	199
10	Sodium nitrate Superphosphate	220 470	..	368	185	132	228	212	114	115	147
11	Potassium sulphate	125	..	292	247	127	222	229	154	114	166
12	Superphosphate	470	..	292	198	123	206	313	125	142	193

Since only one check was used in each of the two series, no conclusions are justified except where differences are very striking. Nitrogen, particularly when applied near the blooming time, seems to have given beneficial results. As to the other elements, there is no conclusive evidence of any benefit. There is no reason for assuming that a check between plats 8 and 9 or between plats 10 and 11 would have yielded approximately the same amount of fruit as plat 6. The results do not justify a conclusion that potassium and phosphorus have given no benefits whatever; but certainly no large benefits have resulted from the use of these two elements. According to this author application of nitrogen increased the size of the berries; but, when the season was dry, it reduced their firmness. In that section ploughing under a crop of clover or alfalfa before the plants are set gives markedly beneficial results as to plant growth and yield.

Dyer and Shrivell (597) did not seem to find beneficial results in their soil in England when potassium was added to plats already receiving small quantities of manure, though potassium seemed beneficial when added to phosphorus where no manure was applied. At first they seemed to find potassium harmful. It is barely possible that some plants were killed by having too much of this element around them before it was thoroughly disseminated in the soil. It would be safer in using potassium to work it into the soil before the plants are set. It is doubtful, however, if it can often be used profitably in soils in America.

Wright (740) gives results of some experiments with the effect of lime on strawberries. In all cases lime seemed very injurious. It seems probable that the strawberry does best in a soil slightly acid, though Hartwell and Damon (618) seemed to find in Rhode Island slightly beneficial results from liming. The plant from experience is known to be tolerant of acidity in the soil.

It will be seen that our evidence concerning the response of strawberries to fertilizers is very unsatisfactory. The errors involved in experimenting with strawberries are very great for the reasons suggested and for the additional reason that when the berries are grown in a matted row, it is very difficult to have two rows of the same width. The way the cultivator happens to run when the plants are setting may influence the width of row more than will any fertilizer treatment. Generally some of the rows will be appreciably wider than others, and thus having more plants will yield more. In the matted row system the better plan is to have each of the plats cross a number of rows. This, however, gives many short rows, and increases the difficulty of getting the records. It would seem probable that more accurate results would be obtained with strawberries in the hill system, using very small plats and having each treatment given to a number of plats distributed in regular order over the experimental area.

From experience, and from the studies of Brown, we can be certain that before the plants are set ploughing under a crop of succulent green highly nitrogenous vegetable matter, like immature clover or alfalfa, is desirable, particularly in obtaining a good stand of plants. Farther than this ploughing under of manure or green crops before planting, there seems little to be expected from the application of fertilizers to strawberries except in soils that contain some element in exceptionally small quantities. However, on account of the great value of the crop, very small increases would make the use of fertilizers profitable.

Cranberries and Blueberries

Cranberries are generally grown in bogs consisting of a layer of peat or peat and sand from a few inches to seven or eight feet thick over sand, beneath which is usually a layer of hard pan. This last is generally responsible for the bog condition. Such a soil might be expected to be somewhat low in mineral elements and sometimes in available nitrogen. Fertilizer experiments under these conditions should be very interesting.

Franklin (603) has studied the response of this crop to fertilizers in the bogs in Cape Cod, Massachusetts, and found no conclusive evidence of response to any element. Certainly if there was response, it was so small that it would not pay for the fertilizers and extra labor.

Malde (669) made some tests in Wisconsin bogs in which he found some evidence of response to applications of each element, but very evident response to application of sodium nitrate and acid phosphate. He recommends 240 pounds of acid phosphate, 80 pounds of sodium nitrate, and 80 pounds of potassium sulphate to the acre.

Headlee and Beckwith (620) and Beckwith (566) have reported results of experiments in New Jersey bogs. Their most consistent results were with what they term "Savannah" bogs, the soil of which is sand with enough silt to give it a dark appearance. In this, applications of nitrogen and phosphorus were beneficial, while results from potassium were less marked. About thirty pounds of nitrogen and eighty pounds of phosphorus pentoxide seemed the optimum amounts of these elements. Much above this amount of nitrogen gave too much plant growth with reduced fruiting. Sodium nitrate was found to be a very satisfactory form of nitrogen, and there was no advantage from using dried blood as a source of part of the nitrogen. Ammonium sulphate alone was not found satisfactory. Phosphorus in raw rock was not available until the second year, but in the second year it gave good results. Phosphorus in acid phosphate was immediately available. The cranberry is grown in acid soils, yet Beckwith seemed to find that the soil may be too acid. While his work in that line is not completed he has suggested that liming some of the New Jersey bogs, provided the soil is left slightly acid, is beneficial.

Beckwith (565) found a fertilizer containing sodium nitrate, dried blood, steamed bone, acid phosphate and Nebraska potash very greatly to increase the yield of blueberries (*Vaccinium corymbosum*) growing in a sandy soil in which the plants had a yellow unhealthy appearance. Sodium nitrate alone, 250 pounds to the acre, seemed to be injurious as to yield; and sodium nitrate, acid phosphate, and Nebraska potash caused a greatly increased yield but less than with the mixture first mentioned. As to what element is responsible for most of the gain, there seems to be no information furnished except that nitrogen is not responsible for all of it.

Summary. Results from field experiments with fertilizers are by no means as conclusive as we should like; yet certainly from them we have obtained some valuable information as to the response of different fruit crops. The striking result is that in some soils where field crops may show marked response to applications of some of the elements, there is no response to any element in the case of some fruits, and response only to nitrogen in the case of others. In soils exceptionally low in an element there is likely to be response to its application. Thus with Citrus trees in Porto Rico there seems to be response to all elements. According to Kinman (648) this is true also of cocoanuts there. Cranberries, at least in some bogs, respond to applications of all elements.

Many of the fruits are tolerant of an acid condition in the soil. In fact there is no conclusive evidence that any common deciduous fruit is not; though there is a suggestion that in an acid soil gooseberries and currants are benefited by applications of lime.

With the exception of the strawberry and possibly the cranberry, all the common deciduous fruits seem to make no response to applications of phosphorous in soils in which corn, oats, and other common field crops will make marked response. We have no published conclusive evidence as to whether or not this is true of Citrus fruits.

Application of potassium, unless it may be in a soil so low in that element that the plants and the fruit have an unhealthy appearance, does not seem to have any influence on the color of the fruit. If potassium is exceptionally low in a soil, fruit trees may make a rather striking response to its application. However, in most American soils if there is a response, it is not so striking as to be measurable in field experiments; though there is a slight suggestion running through many experiments that even in soils rather rich in potassium there may be a tendency for fruit plants to respond in growth and yield, particularly in size of fruit, to applications of that element. As to whether or not there is such a response, we can probably learn, if at all, only by means of experiments in which preliminary records are kept of the trees under uniform treatment, in order that trees of like capacity may be found and carefully paired before the difference in fertilizer treatment begins. We know, however, that with most fruits in soils rather low in potassium very high yields may be obtained without its application. And, the application of potassium seems to be one of the last features to which fruit growers in most sections of America should give attention in their efforts to increase the yield and quality of fruit borne in their orchards.

Details as to the responses of individual fruits to applications of nitrogen have been discussed. Reviewing generally, nitrogen is the element most often deficient in the soil and the application of which will most often cause profitable increase in fruitfulness. In orchards in sod in nearly all soil types, practically all fruits that can be grown under such conditions will make large response to applications of nitrogen. However, not all fruits will respond to applications of nitrogen in a tilled soil of medium fertility. With apples, with blackberries and probably with pears, grown under average conditions as to moisture and soil aeration, for there to be response to applications of nitrogen the soil must be much lower in available nitrogen than with corn and some other field crops. On the other hand, peach and cherry trees and red raspberry plants seem to respond to applications of nitrogen in any soil in which common field crops will respond. Citrus trees for good yields require application of nitrogen in soils in which even peach trees will give good results without such application. Very large applications of nitrogen as well as of potassium may cause injury to trees. The margin between the maximum amount to which the trees will respond and the amount which will cause injury is wider with some fruits than with others and is generally much wider in a compact clay soil than in an open sandy or gravelly one. Unless the water supply is limited or the sunlight unusually intense the optimum quantity of nitrogen in the soil to which the trees will respond will cause a reduction in color intensity with kinds such as the apple and the peach that require sunlight to develop red color. This is due, in the main, to the shade caused by the dense foliage. And the ripening of the fruit is generally delayed.

With strawberry and apparently with cranberry plants a very large nitrogen supply at certain times of the year may cause excessive vegetative growth and a reduction in fruiting. With some varieties of red raspberries, a very large supply of available nitrogen may cause the growths of such a thick mass of suckers that, while fruiting is not reduced, it is not appreciably increased. With young trees of most kinds a very large nitrogen supply may, if the water supply is abundant, cause them to be a year or two later in beginning fruiting, the trees thus becoming large enough to bear a maximum crop sooner. And with mature trees pruned very severely and having an abundant water supply, a large nitrogen supply may cause the wood to be too highly vegetative and unfruitful; probably in a section such as England, where the rainfall tends to be more nearly adequate and transpiration rather low, heavy application of nitrogen might cause such a condition with mature trees of some varieties even without excessive pruning. However, in most sections of America apparently with all kinds of tree fruits, with trees that have reached the heavy bearing age, if the pruning is not excessive, it is practically impossible to apply enough nitrogen to throw them out of fruiting unless enough is used for it to be so toxic that the leaves fall. With nearly all kinds of tree fruits, therefore, the grower's problem as to the amount to apply is not generally associated with any danger of causing too much vegetative growth for fruitfulness. Rather his problem is generally to find the largest amount of nitrogen to which the tree will tend to make a profitable response, avoiding injury to the color or quality of his fruit and avoiding toxic effects in his trees from excessive quantities.

With some fruits, particularly the apple, he has problems also as to the possibility of so regulating the soil nitrogen supply as to cause annual bearing with varieties having a tendency toward alternate bearing. There have been some suggestive results with fall application; also with causing the soil nitrate supply to be low during blooming time in the heavy bearing year and high throughout the lightly bearing or nonbearing year. The amounts of carbohydrates and of various nitrogenous compounds in the tissue at critical times, such as when the fruit is setting or when fruit buds should be forming, may be influenced more by the time of application of nitrogen, the time of ploughing, or the nature of the weather than by the total amount of nitrogen applied or the total amount of vegetative growth made.

CHAPTER 15

EFFECT OF DORMANT PRUNING ON GROWTH AND FRUITING

In the discussion of pruning to be undertaken in the next few chapters the greatest stress will be placed where problems are involved. It will not be the purpose to emphasize the importance of various practices the wisdom of which is evident, such as cutting out dead or broken branches or cutting the branch close enough to leave no stub to rot back into the tree.

Pruning may be done for its direct effect on the growth or fruiting of the tree or plant, or it may be done to shape the plant. In pruning to shape, the growth and fruiting will be influenced on account of the necessary cutting away of wood in shaping, even though the form desired, such as open head or central leader, may in itself have little influence on fruiting. Thus we must know the effect of the cutting necessary to obtain a given form before we can discuss its value; and in studying the influence on growth and fruiting of a given form due allowance must be made as to the influence of the pruning necessary to train the tree to such a form. For example, if the only question involved as to the high or low head were that of convenience in caring for the tree, the problem would not be difficult; but large amounts of cutting must be done to secure the high head; and this may greatly influence fruiting. We cannot therefore discuss training intelligently without first gaining knowledge of the effect on the growth and fruiting habit of the tree of any cutting back or cutting away of branches.

The invigorating effect of cutting off parts. The most evident effect of cutting away parts of a tree in pruning is an increase in vigor. Thus, generally, near the point where a portion is cut off there will grow vigorous shoots; or all of the shoots on a branch adjacent to one removed may be more vigorous, continuing to grow later, and having larger individual leaves. Generally the leaves will be of a deeper green color. However, in the case of peaches, with which leaf color differences are very striking, the color is not so deep as that of trees whose vigor of growth has been increased to about the same extent by their being fertilized with sodium nitrate; though, with bearing pear trees, rather severe pruning may cause a deeper leaf color and a greater increase in vigor of shoot growth than can be caused by application of nitrogen, even though the soil be one in which pear trees will make rather marked response to nitrogen. This response of old pear trees may be due to the cutting away of bloom buds and the consequent reduction in the amount of bloom relative to the size of the tree. Heavy blooming reduces leaf color and appearance of vigor in trees.

The increase in vigor is in proportion to the amount of pruning. Thus if the trees are pruned very severely, or "dehorned," new shoots, "watersprouts," six feet long or more may grow; and, while the unpruned tree that is old enough to be in bearing will cease shoot length growth within a few weeks after the growth starts, these "watersprouts" on pruned trees may, in extreme cases, grow until frost.

Cause of increased vigor following pruning. Perhaps we cannot say with certainty what is the cause of this increased vigor of pruned trees or branches. One of the most common explanations given is that a smaller number of growing points are making use of the stored organic food. It is, of course, true that the number of growing points is reduced; and since much of the wood that is left is old and contains no active buds it is probable that, during the first few days of growth, the number of growing points is reduced more than is the organic food supply. Further, it is generally the younger wood that is cut away; and this, while being as rich in organic material as the wood not removed, will have a larger cambial area in proportion to its weight. Apparently, by the cutting, both the number of growing points and the amount of cambial area are thus reduced more than is the carbohydrate supply. However, if as a result of the pruning there were an increased organic food supply and that supply continued to be larger late in the growing period, all parts of the tree including the roots should show an increased growth. Yet we shall see later that root growth is markedly decreased by pruning. The organic food supply for the roots or some other material essential for root growth, therefore, must be reduced; and so, while there may be an increased organic food supply large enough to cause a greater vigor in the initial growth, it does not seem that such an increased supply continues late enough to cause the increased vigor to continue as late in the season as it normally continues.

It may be held that if, for the initial spring growth, there is more organic material, as a result of the pruning, the better conducting tissue and larger foliage at the beginning may influence the growth later. It should be said, however, that this increased vigor results even when the pruning is done at the time when the organic food supply seems to be at the minimum. Thus we have seen in Chapter 1 that starch seems largely to disappear soon after growth starts and that the concentration of soluble organic materials is greatly reduced. And (Table 9) for the year 1916 at Ithaca, New York, the concentration of soluble materials in the sap was lowest from May 18th to June 1st; yet trees pruned in that year on June 1st showed the markedly increased size of leaves and the later continuance of growth that was shown by trees pruned earlier. If the characteristic invigorating effect follows pruning at a time when the reserve organic food supply is so low that the tree must depend upon that formed by the leaves on the new growth, it does not seem that this greater vigor can be caused by an increased organic food supply; for the leaf surface is reduced by the pruning. The number of leaves is so greatly reduced that the total area on the pruned tree or branch is reduced, even though the individual leaves are larger. When the leaf surface is reduced, the supply of organic nutrients may also be expected to be reduced.

This reduction in leaf surface suggests a cause of the increased vigor; for transpiration also should be reduced. The root system during early summer would be about as large on the pruned as on the unpruned tree. The water supply for the twigs and leaves left should therefore be increased. In like manner, since the number of growing points is reduced by the cutting away of twigs carrying buds, the demand for soil nutrients may be reduced. Since the absorbing power of the roots remains about the same, during the early part of the season at least, the supply of soil nutrients may be larger for each growing point than it would have been without the pruning. We have seen that nitrogen is most liable to be present in insufficient quantities. In a soil deficient in nitrogen, if pruning increased the vigor by increasing the supply of nitrogen and other mineral nutrients, the foliage should be of a deeper green color. With peaches this test would be very dependable. Where the vigor is increased by pruning the color is slightly deeper. I have pruned peach trees severely and fertilized others with nitrogen in a soil very poor in that element. Even when the vigor as measured by twig length, leaf size, or duration of shoot growth was increased more by the pruning than by the fertilization with nitrogen, the leaf color was not nearly so deep a shade of green as when nitrogen was applied. Unquestionably there was some increased nitrogen supply to the part remaining of the pruned trees, but not enough to account for the increased vigor. It seems probable that under average soil conditions the larger part of the increased vigor of shoots caused by pruning is due to increased water supply; resulting mainly from the fact that the transpiring leaf surface is reduced while the absorbing power of the roots and the water-conducting power of the tree remain temporarily about the same. In fact the conducting power of the tree may be slightly increased, since the resistance should be reduced by the cutting away of wood and bringing the growing point nearer the roots. That the water supply to the leaves is increased by pruning is suggested by the work of Cullinan (417). He found a greater transpiration from a given leaf area in the case of a severely pruned tree. It seems probable that the transpiration was greater because the water supply was larger. It seems possible, also, that pruning, particularly cutting back branches, may increase the efficiency of the tissue in conducting water or mineral nutrients. By the cutting back of a branch the distance through which either water or nutrients must move is reduced and the new wood formed may be more effective in conducting either.

However, it cannot be said with certainty that pruning may not increase the amount of some growth-promoting substance, or reduce the amount of some growth-inhibiting substance; though we have no evidence that it does.

If the mere presence of large amounts of carbohydrate material relative to the amount of nitrogenous material in the tissue tends to inhibit growth, it may be that a large part of the increase in vigor of growth is due to the reduction in carbohydrates and the consequent narrowing of carbohydrate nitrogen ratio. However, this increase in vigor follows pruning with trees growing in soil so rich in available nitrogen that they will make no response to application of additional quantities. This is true even if the pruning is done soon after the bloom when the supply of carbohydrates is very low.

What has been said applies to trees that are not blooming heavily. Unquestionably a large part, if not the largest part, of the invigorating effect of pruning, particularly cutting back of trees bearing many fruit buds at the ends of the branches, is due to removal of such buds and the consequent reduction of the depleting effect that accompanies blooming and the setting of a heavy crop of fruit.

Kraus (847) and Gardner (811) have called attention to the fact that the increased vigor of growth following pruning is observed mainly near the point where the cut is made. Thus let us say a branch is cut back very severely: the growth near the point where the cut is made may be very vigorous, but the twigs further back on the branch may be invigorated only slightly; and those on adjacent branches, possibly, not at all. This would be expected with bearing trees if a very large number of fruit buds were cut away from the end of the branches. Not all the invigorating effect of pruning is localized, however, as we shall see in a more thorough discussion of this subject in Chapter 17.

Effect of pruning on the size of the fruit. This invigorating effect of pruning might be expected in some cases to increase the size of the fruit.

Of course an increase in size caused by pruning may result from a reduction in the number of fruits. With trees that bear an excessive number of fruit buds to the ends of the branches cutting back or thinning out of small branches may be a much more effective means of increasing size than is thinning the fruit after it has set.

In some cases, however, pruning seems to increase the size of the fruit for the same reason that it increases vigor of leaf growth of non-fruiting trees. If such increased vigor is due to the increased water supply to the part left, and if water supply is the limiting factor for fruit growth, as it will tend to be in a dry sunny season, then pruning it seems will increase the size of fruit. In a sod orchard in Missouri (62) pruning increased the size of the fruit of Jonathan apples even when the pruned trees bore as many fruits as the unpruned trees. General observations indicate that this is a very common result of pruning old fruit trees. The effect of severe pruning in increasing the size of grapes is of course very marked. On the other hand, Pickering (872) found in England no increase in size of apples due to pruning during the first fifteen years from the graft. In fact the fruit on the lightly pruned trees averaged slightly the larger.

I have observed rather severe pruning to reduce the size of early (Sneed) peaches in Missouri. In this case the peaches were ripening while the shoots on the pruned trees were still growing rather rapidly. The water supply at that time (late June) was good; and it seems probable that the limiting factor was the supply of organic food. It would be expected that the pruned trees with a better water supply to the parts left, and probably also a better nitrogen supply, would continue growing later, and during this rapid growth would use organic nutrients so that the supply of these would remain lower than it would have been if the trees had not been pruned severely.

We should expect, therefore, that pruning might have a different effect on the size of the fruit depending upon the number of fruit buds, the ripening time, the time length growth ceases, and the adequacy of the water and nitrogen supply. If the supply of water or nitrogen or of both were insufficient for development of large size in the fruit, then pruning should increase the size. On the other hand, if both water and nitrogen were present in abundance and the fruit ripened after growth had ceased, the supply of organic food also would probably be adequate and pruning might not influence the size of the fruit except by reducing the numbers on trees with far too many fruit buds. However, if the supply of water and nitrogen should be sufficient for good growth and the fruit should ripen early, pruning, by prolonging the period of vigorous vegetative growth, might reduce the supply of organic food to the fruit and thus reduce size.

Effect of pruning on the size of young trees. In spite of the invigorating effect just discussed, pruning, at least when the tree is young, is a dwarfing process. This fact has been emphasized by Pickering (872), who studied the effect of severe cutting back of the twigs, moderate cutting back, and less than normal cutting, as compared with no cutting back. With a large number of trees the size of the tops of those receiving no pruning was, at five years of age, thirty-three per cent, and at ten years of age seven per cent greater than that for trees receiving what he calls normal pruning, while that for those receiving much more than normal pruning was thirteen per cent less than that for trees having normal pruning. There were for each of these treatments eighteen or more trees, six of each of three varieties. When the trees were eleven years of age it was necessary to cut out three trees of each variety in each plot. The trees, together with eighteen-inch portions of all the roots, were weighed. The trees receiving very little pruning were found to average approximately forty-nine pounds heavier than those receiving more than normal pruning. The prunings had been weighed only during two seasons when on the severely pruned trees it averaged two and one fourth pounds to the tree. This indicates that about twenty-seven pounds to the tree may have been removed during the eleven years in case of the severely pruned trees. The pruned trees seem to have made twenty-two pounds less growth than the unpruned ones. We shall see later that the difference in the amount of fruit produced was even greater in favor of the trees with little pruning; and so the total amount of dry matter produced during the eleven years was markedly greater in case of the trees receiving little pruning.

Alderman and Auchter (20), also, have studied the effect on the growth of the trees of heavy, moderate, and light cutting back of the branches. Their results seem to indicate that while the heavy pruning reduced the total growth after the first two years, whether the results were measured as total shoot growth or as trunk diameter, the pruning during the first two years did not reduce either shoot growth or trunk growth. They conclude, therefore, that such heavy pruning is undesirable after the first two years, but, that since it does not reduce growth during the first two years, it may be desirable, in that it tends to give better form to the trees. Even if these results should be confirmed by further evidence, it does not follow that pruning at that time may not reduce the size that the tree will attain during the next year or two. This point will be treated further after we have studied the effects of pruning on leaf surface and root growth.

Goethe (818) gives what seems to be very conclusive evidence that by two years of age the trunks of apple trees were appreciably reduced in circumference as a result of heavy pruning.

Tufts (903) in California found young apricot, cherry, peach, pear, plum, and almond trees reduced in size by pruning, the reduction being greater the more severe the pruning.

Bioletti (764) found that the rather severe pruning generally given young olive trees in California and elsewhere greatly reduces their growth. Cullinan and Baker (801) found the growth and the leaf surface of young apple trees to be reduced by pruning. Trees were dug at the end of the first, the second, the third, and the fourth summer in the orchard; and in each case there was a striking reduction in root weight and in top weight as a result of spring cutting back or thinning out of the branches. Cutting back the branches even at planting seemed to reduce root and top growth.

At the Cornell Agricultural Experiment Station (782) more than fifteen hundred trees of various fruits have been in pruning experiments. This included trees of apples, pears, peaches, three species of plums, and two of cherries. In most of these the trees were in shaping experiments and the only difference in the amount of pruning was the difference in the amount necessary to shape trees to different forms. None received anything like as heavy pruning as Pickering gave some of his trees. With all fruits the trees receiving the most pruning appeared to be the smallest, and trunk measurements indicate that until heavy fruiting began they were the smallest. While the evidence that pruning reduces the size of trees is so conclusive that farther data need not be given, the published evidence that this reduction in size is greater than the amount of the prunings, that is, that the total amount of growth is reduced, is perhaps less conclusive. In most experiments cited the trees were still growing and their exact size could not be determined, and in many the weight of the prunings was not kept. For this reason evidence is given under the following topic showing that the total growth is reduced by pruning and also showing why it is reduced.

Effect of pruning on the leaf surface and upon root growth. Studies in Missouri (62) indicate that, with bearing peach trees heavy pruning in the spring greatly reduces the leaf surface that the tree will have by the end of the growing season. Unless it should stimulate greater photosynthetic activity by a given leaf area, such a reduction of leaf surface should reduce the total growth. In other words the trees should be dwarfed by more than the amount of the prunings. More conclusive experiments were conducted at Cornell University (782).

In the spring of 1918 nursery trees, then two years of age, were pruned by cutting away the lower branches and cutting back some of the branches left. Others were pruned less severely, only lower branches being removed, and still others were unpruned. Before the pruning the trees were carefully graded, each unpruned tree being compared with a pruned tree of the same size. The pruning was done just as the leaves were opening. The number of leaves to the tree before and after pruning was determined. Sets of leaves from each tree were measured with a planimeter, the average leaf area for each tree being multiplied by the number of leaves. The following table shows the results.

TABLE 53. EFFECT OF PRUNING ON NURSERY TREES

TREATMENT	Number of trees	Average leaf surface in May, 1918, before pruning (sq. in.)	Average leaf surface in May, 1918, after pruning (sq. in.)	Average leaf surface in September, 1918 (sq. in.)	Average weight of tops plus prunings, May 20, 1919 (grams)	Average weight of roots, May 20, 1919 (grams)
Unpruned	41	756.48	756.48	1737.94	684.0	208.5
Pruned little	33	819.14	470.27	1219.80	558.3	166.9
Pruned much	39	775.70	291.61	895.96	494.3	125.3

The average top weight includes the weight of the prunings. It thus represents the total growth made in the nursery. The pruning rather markedly reduced the leaf surface, and reduced both root and top growth. There had been two years of root and top growth before the pruning was done; the large reduction in size being due to the reduced leaf surface during one out of three summers in the nursery. Similar results were obtained with young peach trees planted in the spring of 1915. Cutting back the 1915 twigs in the spring of 1916 rather markedly reduced the leaf surface and root growth during the summer of 1916. It would be expected that the number of leaves would be reduced at least at the beginning of the season; since by cutting away wood containing buds one cuts away potential shoots or spurs. However, since the shoot length of the pruned trees tends to be greater and the leaves to be larger, without actual determinations, it could not wisely be assumed that the total leaf surface of the tree would be reduced. The reduction is generally greater at the beginning of the season than at the end. Even if the leaf area at the end of the season on the pruned trees should be as great as on the others, it would seem that the total amount of material elaborated should be larger on the unpruned trees, since, for the whole season, they would have a larger leaf surface. However, as we shall see from the work of Gardner, cutting back reduces the number of spurs without greatly reducing the total shoot length. Such pruning, then, would tend to reduce spur leaves rather than shoot leaves. In seasons short enough for the leaves to remain active until frost, it would seem that a given area of spur leaves should produce somewhat the more since spur leaves might be active throughout the season, while the leaves at the outer ends of the shoot may be present during not much more than half of the season; and, in case of peach trees at least, sometimes during much less than half of the season. With apples and pears these spur leaves are small and are clustered in such a way that their importance is likely to be underestimated. With the large and conspicuous leaves of cut-back trees one is likely to reach the conclusion from observation that the leaf surface of the pruned trees is the larger, even when that of the unpruned trees is much the larger.

Table 53 was for young trees. With two lots of apple trees with which leaf surface records were kept until several years after they began to bear even very light pruning reduced the total leaf surface. During the first few years in the orchard both spur and shoot leaf surface was reduced, but later the reduction was only in spur leaves. There was some complication; for unpruned trees bore the most fruit; and fruiting, also, reduces the leaf surface.

Pruning, in the main, reduces the total leaf surface of a tree by reducing the number of spur leaves and leaves of small lateral shoots to a greater extent than it increases the size of the leaves on strong terminal or nearly terminal shoots; that is, by reducing the number of buds opening more than it increases the amount of growth from individual buds. The average length of life of the leaves on the spurs and short shoots may be greater than that of leaves on long vigorous shoots; for they are formed earlier in the summer and live through the period of longest summer days; and, if a given area of such leaves is as efficient as the same area of leaves on vigorous shoots, the amount of food synthesized during a summer should be greater. However, a larger percentage of such leaves than of terminal shoot leaves may be in the shade or in positions otherwise unfavorable for photosynthesis. Some light was thrown upon this problem for climates such as that of Ithaca, New York, by an experiment with Early Richmond cherry trees at Cornell University. The trees were weighed when they were planted in the spring of 1917; all prunings were weighed each year, and in the spring of 1922 the trees were dug; care being used to get all of the roots. The wood of each tree was divided into lots as follows; twigs, younger branches, older branches, part of trunk above the surface of the soil, part of trunk below the surface of the soil, larger roots, smaller roots; and moisture determinations were made for each kind of wood. Thus the total dry matter of each tree when dug could be estimated; and by deducting the estimated dry matter of the tree when planted from that when dug up the total dry matter (except that in the leaves) produced by the tree during the five years of growth could be estimated. Because of frosts only a very few fruits were borne by any tree. The leaf surface of each tree was of course determined each year, shoot leaf surface and spur leaf surface being kept separate. Twelve trees were left unpruned and 12 were pruned rather severely each year, the twigs being cut back to from 20 to 40 per cent of their original length.

The growth of the pruned trees was mainly in long shoots that continued growing well into July, while that of the unpruned trees was distributed among a much larger number of shoots that ceased length growth considerably earlier in the summer. With the unpruned trees 20.3 per cent of the leaf surface was on spurs. Of course a considerable percentage of the shoot leaf surface was on small shoots, some of which were partly shaded and otherwise in inferior positions. With pruned trees 7.2 per cent of the leaf surface was on spurs and there were few short shoots; a considerable percentage of the leaf surface at the base of the strong shoots was in partial shade. An abundance of nitrogen was applied to the soil; and it is probable that the results were in no way complicated by lack of mineral nutrients. Data are given in Table 54.

With these cherry trees in the climate of New York the average square inch of leaf surface on the unpruned trees seems to have been as productive as the average on the pruned trees or a little more productive. Of course this applies only to dry matter left at the end of the experiment. We do not know with which kind of tree, pruned or unpruned, the larger percentage of the dry matter synthesized would be used in respiration.

In the climate of Ithaca unpruned cherry trees in good soil cease length growth rather early in summer and shed their leaves rather early in autumn; and those pruned rather severely cease length growth earlier in summer and shed their leaves earlier than do some kinds such as peach trees or trees of Baldwin or some other varieties of apples. It seems probable that under the conditions that prevailed in this orchard the production by a given leaf area would be reduced more by severe pruning of such later growing kinds than by such pruning of these cherry trees; and that the reverse might be true of kinds such as the Oldenburg apple that cease growth early in summer and shed their leaves early in autumn. It seems probable, also, that where the growing season is shorter than that at Ithaca the production by a given leaf area of the pruned trees may be still farther reduced as compared with that of unpruned trees, and that

TABLE 54. EFFECT OF PRUNING ON GROWTH OF ROOT AND TOP, ON LEAF AREA, AND ON EFFICIENCY OF LEAVES, OF EARLY RICHMOND CHERRY TREES

	AVERAGE FOR TREES PRUNED	AVERAGE FOR TREES UNPRUNED	PER CENT OF REDUCTION CAUSED BY PRUNING
Total leaf surface of tree during five years........	64,824.7 sq. ins.	98,023.4 sq. ins.	33.9
Green weight of top.......	35.36 lbs.	63.93 lbs.	44.7
Green weight of top plus prunings...............	43.93 lbs.	63.93 lbs.	31.3
Green weight of roots......	14.22 lbs.	28.14 lbs.	49.5
Total dry matter as top....	22.26 lbs.	34.10 lbs.	34.7
Total dry matter as roots..	5.55 lbs.	11.12 lbs.	50.1
Dry matter as top produced by 100,000 sq. ins. of leaf surface.................	34.64±0.51 lbs.	35.10±0.54 lbs.	..
Difference............		0.46±0.74 lbs.	
Dry matter as roots produced by 100,000 sq. ins. of leaf surface...........	8.43±0.27 lbs.	11.43±0.22 lbs.	26.25±2.97
Difference...........		3.00±0.34 lbs.	
Total dry matter produced by 100,000 sq. ins. of leaf surface.................	43.17±0.60 lbs.	46.53±0.61 lbs.	7.25±1.85
Difference............		3.36±0.86 lbs.	

where the growing season is longer and the leaves of unpruned trees tend to fall before they are injured by frosts, or where inadequate water or nitrogen supply or other unfavorable soil conditions cause the leaves of unpruned trees to fall before they are injured by frost, the production by a given leaf area of trees that are caused by pruning to grow later and hold their leaves later may be increased as compared with that of unpruned trees.

It should be emphasized that the total dry weight of a tree may not be an accurate measure of its growth in volume or of its bearing surface. The unpruned tree, if it ceases length growth, and cambial growth much earlier than the pruned may, because of the greater accumulation of organic substances, form thicker cell walls or deposit in the wood substances such as gums that add to its weight but that may not be of any value to the tree when under cultivation. It seems probable, however, that the difference in weight due to such a deposition is small; and total weight is probably the best measure of growth that we have.

It is interesting to note that with these trees severe pruning reduced root growth to a considerably greater extent than it reduced top growth. The percentage of reduction in weight was greater for roots than for tops even when the weight of the prunings was not added to that of the tops at the end of the experiment. With some Elberta peach trees, also, pruning in the fifth and sixth spring in the orchard reduced root growth much more than it reduced top growth. These peach and cherry trees were older at the end of the experiment than were any of the trees previously mentioned whose root weights were determined. It may be that with trees this age or a little older pruning increases the vigor of top growth and reduces root growth to a greater extent than with trees only two or three years old. Of course, the tops were reduced in size very appreciably, due to the loss of the wood removed in prunings. The reduction in root growth may be considered as an adjustment to the reduced size of the top. There is an interesting question as to how pruning these peach and cherry trees, which were old enough for the unpruned trees to have ceased to make vigorous annual shoot growth, reduced root growth more than it reduced top growth. In other words how was this adjustment of root and top brought about. If the water, mineral nutrient and organic nutrient supplies were available for the whole tree, why would not all parts grow with equal rapidity? By what means was growth stimulated in the top and reduced in the roots. It seems probable that the increased water and nitrate supply due to the pruning made conditions in the top so favorable for growth that an increased percentage of the organic or organic nitrogenous materials was used there and a reduced percentage moved to the roots. We have seen in Chapter 4 that the root growth is larger in proportion to the top growth in sod orchards than in cultivated orchards; that apparently in very moist soils, where the water supply is good, the relative size of the root systems is smaller than in a non-retentive gravelly or sandy soil; that on a wet year when the water supply is very abundant and growth continues very late, there is some evidence to the effect that top growth is made at the expense of root growth; and that when nitrogen is applied to young peach trees the root growth is smaller in proportion to the size of the top. If the effect of pruning is, by reducing the evaporating surface and the growing areas, to increase the water and nitrogen supply to the growing areas left, then we should expect that pruning should stimulate top growth at the expense of root growth.

Pruning may also increase the conducting power of the wood by reducing the distance through which water and nitrogen must move and possibly by causing the formation of wood that is more efficient in conduction.

In the light of the fact that pruning may temporarily reduce root growth when top growth is reduced but slightly, it is interesting to examine the statement by Alderman and Auchter (20) that pruning during the first two years does not dwarf the trees. In New York pruning dwarfs even young trees in the nursery, as well as young trees from the time of planting. Why were different results obtained in West Virginia? In the first place the variation among trees is so great that it is not impossible that the reason their trees did not show the dwarfing during the first two years is because it had not become large enough at the end of two years to be detected among the variations caused by other influences; or the measurements used may not have given accurate information as to the size of the trees. Even if there were no dwarfing effect in the top, however, it does not follow that, had the pruning been discontinued after the first two years, no dwarfing effect would have become apparent later. Certainly the spread of the top would be smaller in the case of the trees that were cut back. This would cause a reduced framework for the attachment of foliage receiving full sunlight, which condition should certainly tend to reduce growth. Even more important, however, is the fact that if the reduction in foliage by pruning during the first two years had not reduced the top growth it is highly probable that, in the way mentioned above, top growth had been made at the expense of root growth. In this case one should expect the top growth in the year following to be reduced as compared with the trees that had not had the pruning, just as trees that make an excessive top growth in a very wet year are liable to show a reduced growth the year following. It should be remembered, however, that Alderman and Auchter worked in a district where the summer growing season is considerably longer than in New York. It is possible that an apple leaf may not be efficient for the photo-synthetic process throughout such a long growing season, and that the leaf surface formed toward the end of the long shoots on the pruned trees may accomplish as much as the same leaf surface set soon after the beginning of growth in spring. It is thus probable that in West Virginia, the dwarfing effect of pruning is less than in New York. In fact it seems probable that the higher the latitude and the shorter the season in which the tree is growing the greater will be the dwarfing effect of pruning.

Effect of pruning on the fruiting of young trees. Pruning reduces the size of the young tree and should in that way reduce the amount of fruit borne. With kinds such as the apple and the pear that bear fruit mainly on spurs the bearing surface must be reduced more than is the total size; particularly if the pruning is a cutting back; for the twigs that are cut back contain the buds that would open into spurs. Then by increasing the vegetative activity, pruning should tend to cause the tree to continue later in its life a condition of being too highly vegetative for fruit-bud formation. And the experimental results of Pickering indicate that the effect of pruning in delaying fruiting of young trees is even more marked than its dwarfing effect. Thus, when branches were cut back to a length of six, twelve, twenty-four, and thirty-six inches, the numbers of fruit spurs set were in the proportion of 100, 193, 400, and 547. These differences are much greater than the differences in growth. In the mixed orchard previously discussed (grafted in 1898) the trees having the lighter pruning were still fruiting the heavier in 1913, or at 15 years from the graft. There was indication, however, that the more severely pruned trees were gaining on those with less pruning, especially with trees on Paradise stock, which would be farther along in their life cycle. For the fifteen years, however, the reduction in fruiting was more marked than the dwarfing effect; considering the average crop of the harder pruned trees on the crab stock as 100, that for the lighter pruned trees was 208; and on the Paradise stock, for the harder pruned 100, lighter pruned 150. This represents the average crop from 1906 to 1913 inclusive. In another orchard planted in 1905, when the average number of blossom clusters from 1909 to 1914 is considered as 100, that for trees receiving no pruning was 459. In all of this work of Pickering the pruning was primarily a cutting back of twigs.

In the work of Alderman and Auchter (20) pruning reduced the bearing of young trees; and Batchelor and Goodspeed (756) found that pruning back the vigorous upward growth of young apple trees to outgrowing branches reduced the fruiting while they were young. Tufts (903) found that with most deciduous fruits grown in California the severe cutting back of young trees practiced by many growers in that State may delay the beginning of fruiting several years.

All the pruning experiments at Cornell University (782) had to do primarily with shaping. The severest pruning was what seemed to be the minimum necessary to maintain a tree with an open head, the head being composed of five branches, the uppermost one being the largest. The pruning with these trees consisted of a cutting out of branches in excess of five and light cutting back of the secondary branches of all the main branches except the uppermost one. Branches in excess of five coming from the trunk were left if they were in positions such that for a number of years they would not be injurious to the main branches. Most of these had not been removed in 1921 when a progress report was made.

Very few secondary branches were removed, those coming from near the bases of the main branches being left also but being cut back. The uppermost branch received almost no pruning. The trees with which these were compared had practically no pruning, only crowding and distinctly injurious branches being removed. Results with the different fruits are shown in Table 55.

TABLE 55. GROWTH AND FRUITFULNESS OF YOUNG TREES AS INFLUENCED BY THE PRUNING NECESSARY TO OBTAIN A MODIFIED OPEN HEAD

VARIETY	Age in spring of 1921 (years)	Number of trees pruned each way	Average trunk girth in spring of 1921		Average weight of young wood removed by 1921		Total weight of fruit borne to the tree by 1921	
			Pruned little (in.)	Modified open head (in.)	Pruned little (lbs.)	Modified open head (lbs.)	Pruned little (lbs.)	Modified open head (lbs.)
Apples:								
Baldwin	10	13	21.9	20.5	4.4	12.3	419	212
Red Canada	10	1	17.4	16.6	1.9	8.0	644	276
Esopus	10	1	20.6	19.8	3.6	16.6	460	72
Fameuse	10	1	19.6	18.6	3.5	10.7	549	492
McIntosh	10	12	21.2	21.3	2.1	6.8	833	592
Northern Spy	10	8	19.5	19.2	4.0	13.0	210	91
Oldenburg	10	16	17.0	15.8	0.6	3.5	503	433
Rhode Island Greening	10	7	23.2	23.9	4.2	12.0	789	641
Tompkins King	10	7	18.9	17.9	4.2	11.9	311	92
Twenty Ounce	10	12	17.3	17.6	2.2	7.5	337	200
Wagener	10	11	18.3	18.0	1.4	5.6	627	479
Wealthy	10	16	17.1	17.6	1.3	4.4	703	531
McIntosh	7	16	12.0	12.1	0.8	2.2	59	24
Wealthy	7	9	11.3	10.1	0.5	1.3	61	32
Banana	6	6	11.3	9.5	0.9	1.5	94	47
Delicious	6	2	11.2	9.8	0.7	1.8	13	3
Jonathan	6	4	9.9	9.3	0.6	1.5	65	30
Northern Spy	6	12	10.4	9.9	0.7	1.4	..	..
Rome Beauty	6	6	8.3	8.8	0.4	1.2	30	30
Twenty Ounce	6	8	9.9	9.2	0.7	1.3	9	4
Pears:								
Bosc	10	5	16.1	12.9	1.8	3.6	283	44
Clapp Favorite	10	4	17.1	16.4	2.4	12.6	286	232
Kieffer	10	2	16.3	16.0	1.0	10.9	427	515
Seckel	10	3	16.2	11.8	1.4	6.2	240	50
Sheldon	10	5	18.0	14.8	2.1	6.9	181	50
Plums:								
Abundance	9	2	20.0	17.7	0.4	6.9	144	101
Bradshaw	9	3	19.4	18.2	1.4	6.5	81	42
Burbank	9	5	19.9	18.6	2.5	11.4	417	369
German *Prune*	9	5	17.8	16.6	1.3	7.2	131	128
Reine Claude	9	4	18.9	18.2	0.9	5.0	214	197
Shropshire	9	5	15.5	14.7	0.7	4.6	217	128
Cherries:								
Montmorency	6	4	14.2	12.9	1.4	2.3	21	16
English Morello	6	2	9.2	9.4	0.4	1.1	19	23

Enough pruning to obtain a modified open head apparently caused a reduced yield with every variety except Kieffer pear; and with that variety not enough trees were used to give significant results. In fact, with no variety were there enough trees to furnish results significant if only one variety was considered, unless the differences were very large. However, the total number of trees pruned each way was rather large and since with practically all varieties the pruned trees yielded the smaller crops the results seem very conclusive. The total weight of fruit borne on the moderately pruned trees of all varieties was less than two thirds of that borne by the same number of trees having still less pruning.

It is interesting to compare the apple and plum trees. With the apple trees, except those too young to have borne much, the amount of fruit was considerably reduced by pruning, though the size of the trees, as indicated by trunk girth, was not measurably reduced. Earlier in the life of the orchard the pruned apple trees seemed considerably smaller than the unpruned; but after the trees began to bear heavy crops the difference seemed to disappear. With the plums, however, the pruned trees were, in 1921, still clearly smaller than the unpruned ones. It seems probable that this difference between the apple trees and the plum trees may be explained by the differences in fruiting habit. At Ithaca the apple trees, except with a few varieties, tend to bear the fruit on spurs, and we have seen that with such kinds the fruiting spur system may be reduced in greater percentage than is the total size of the tree. The unpruned apple trees seem therefore to have borne enough heavier crops that the dwarfing effect of this greater fruiting has tended to be equal to the dwarfing effect of pruning. With the plums, fruit is borne on both twigs and spurs and the reduction in fruiting caused by pruning seems to have been about equal to the reduction in the size of the tree. Pickering reports experiences with dwarf trees with which the greater fruiting of the unpruned trees dwarfed more than did the pruning of the others; and Grubb (821) reports similar results. When, because of the climate or because of other conditions, much fruit tends to be borne from twig axillary or terminal buds of apple or pear trees, if pruning should prevent the formation of such axillary and terminal fruit buds, or should remove most of them before the bloom, it might actually cause the pruned tree to outgrow the other. This applies to light pruning. It is seldom that fruiting dwarfs the young tree as much as does severe pruning.

It may be that with a few of the apple trees in this experiment pruning reduced fruiting by promoting the development of a vegetative condition unfavorable for fruit-bud formation. However, with most of them, the wood left was highly fruitful as Figure 20 will show. With most, if not with all, pruning seems to have reduced fruiting by reducing the bearing surface, the number of spurs located in positions favorable for healthy development. And that seems to be the explanation of the results of

Batchelor and Goodspeed, where cutting back the rank growing branches in the top to an outgrowing branch reduced the fruiting. It does not seem that this could have been because of any tendency of such a slight amount of pruning to encourage vegetative growth at the expense of fruit-bud formation. The reduction in fruiting was probably because wood was cut away that would have borne fruit if it had been left. Certainly in case of the Reine Claude and Burbank plums in the Cornell experiment the reduction in yield could not have been a result of any tendency of the pruning to encourage vegetative growth rather than fruitfulness; for all the trees bloomed so heavily that either an excessive crop was borne or thinning had to be done. The difference in the size of the crop resulted entirely from the difference in the size of the pruned and unpruned trees. However, it is certain that pruning can be severe enough to cause a vegetative growth unfavorable to fruiting; and with young trees it may be so even in practice. This was true for a few years with some of the trees of Pickering and of Tufts and probably with some of those of Grubb; and I have pruned many young trees severely enough to cause that effect. However, except with very young trees where the water and nitrogen supply is more than ordinarily abundant, only rather severe pruning seems to produce such an effect.

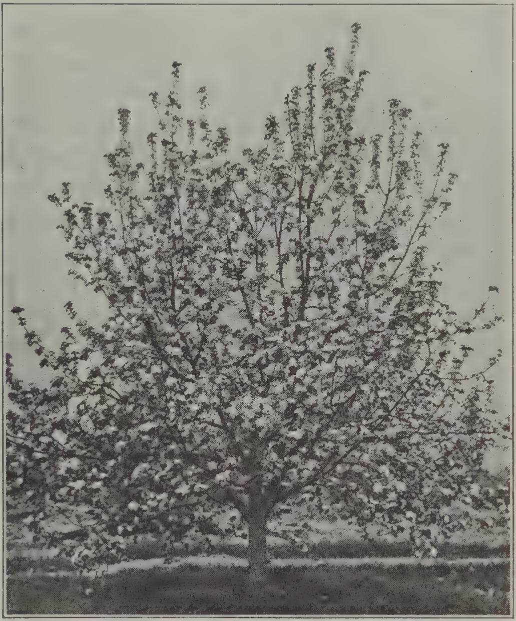

Figure 20. Young Wealthy apple tree pruned to modified open head, the uppermost branch being the largest. The amount of pruning necessary to obtain such a form reduced the amount of fruit borne by young trees, not by promoting a condition in the wood unfavorable for fruiting, but by reducing the bearing surface.

This is not an exhaustive review of the experimental evidence concerning the effects of pruning on young trees. However, much of the evidence is applicable rather to specific practices with specific fruits than to a consideration of the general responses of fruit trees to pruning and will be discussed in a later chapter.

Effect of pruning on the growth and fruiting of mature trees. The invigorating effect of pruning is more pronounced with old than with young trees. We have seen in Chapter 1 that trees tend to cease length growth each year slightly earlier than in the preceding year. The tendency is very marked with the peach, the Japanese plum (*Prunus salicina*) and the currant. With most kinds an age is eventually reached when very little or no shoot growth is made. This condition is reached at an earlier age if the water supply or the nitrogen supply is deficient or if conditions generally are favorable for heavy blooming and fruiting to the very end of the branches. Shortening the branches tends to reinvigorate such trees. In addition to the general invigorating effect old weak wood is replaced by younger less spurry and more vigorous wood that may be more efficient in conducting water and nutrients. Such pruning tends to prolong the life of the trees, the life of peach trees in some cases being markedly prolonged. Thus in New York a survey indicated that peach orchards under average conditions begin to decline at about thirteen years of age, yet orchards with which careful renewal pruning is practiced may show little if any decline at twenty-five years of age.

Varieties of apples such as Wealthy or Wagener that begin bearing young and bear on the terminal wood reach rather early in their lives a stage when very little wood growth is made; and, with some varieties, the fruit is very small. Renewal pruning is more certain to be beneficial with such varieties. Wealthy is generally considered a good variety for fillers, where the trees are cut out while they are rather young; but the fruit on older trees may be too small for marketing. Yet some growers maintain the vigor of growth and the size of the fruit by pruning rather severely after the trees are older. Thus in the orchard of Messrs. Stanton and Norman Jack, of Chateauguay Basin, Quebec, Wealthy apples of good size are obtained from old trees as a result of their pruning back the ends of the branches to a considerable extent each year.

Pickering (872) found pruning back the wood of fifteen-year-old trees (probably dwarf trees) markedly to increase the total amount of shoot growth made. We could not conclude from this that pruning had increased the total amount of growth. It is not impossible that the new wood that would have been laid down around the wood that was removed in pruning might, without the pruning, have equalled the amount of wood in the additional shoot growth. The additional shoot growth may, however, be explained in another way. On these trees Pickering found the pruning to result in a marked reduction in fruiting, reducing the crop to less than one tenth of what it would have been without the pruning. Naturally, nutrient material that would have gone to the formation of fruit was available for growth. It is questionable, however, whether light, well distributed pruning through the tops of these trees would have reduced fruiting. Certainly any considerable amount of pruning will reduce the number of spurs in the tree. We have seen, however, in Chapter 10, that when the tree reaches such an age that it blooms very heavily, only an extremely small percentage of the blossoms set fruit. We have seen also that the fruit sets better on the vigorous spurs; and Heinicke (166, 170) found the percentage of flowers to set increased on branches that were pruned back in the spring just before the bloom. Grubb (821) found moderately pruned trees of some English varieties to set fewer blooms but slightly more fruit than unpruned trees. Fruit growers in New York report having caused Anjou pear trees that were dropping all or nearly all of their bloom every year to hold good crops by pruning severely. Alderman and Auchter (20) seemed to find rather heavy pruning to increase the yields of what might be called middle-aged apple trees. Of course we need much more experimental evidence as to just what condition the tree must be in for pruning to increase the crop in the way mentioned above; how severe such pruning must be in order to be effective; and whether such a practice can be continuously effective; or whether to be effective pruning must be so severe that the bearing surface is unprofitably reduced. Thus it might be possible to increase the percentage of flowers to set by so greatly reducing the number of flowers left after pruning that the crop would actually be reduced.

Next to the choosing of a very deep, well-drained, well-aerated but retentive soil, rather severe renewal pruning of bearing trees seems to be the most promising means of reducing the tendency toward alternate bearing. Roberts (292) was able to obtain annual bearing on a few Wealthy apple trees by pruning; and Grubb (821) at least delayed the beginning of alternating by annual cutting back of the twigs about one third to one half their length. By cutting back the small branches throughout the top a longer new shoot growth is formed; and so the supply of new spurs just coming into fruiting is larger; there is increased vegetative activity of the whole tree and particularly of the spurs. Spurs too weak to form flower buds may as a result of the general invigorating effect of pruning and the greater exposure to light become fruiting spurs, and some of the others may be induced to make so much vegetative growth that they will not set fruit buds, but may do so in the succeeding year. Roberts thinks there would be a better chance of bringing about this condition if the pruning were done in the dormant season after the bearing year, this of course to increase vegetation and prevent the formation of fruit buds by so nearly all the spurs in the off year. On the other hand, cutting back in the spring of the bearing year enough greatly to reduce the amount of bloom and to prevent the setting of excessive amounts of fruit might cause the setting of fruit buds in the bearing year. It seems highly probable that by means of enough pruning alternating can be prevented for some varieties. It remains to be determined whether or not this can be accomplished even with these varieties and under the most favorable soil conditions without so much pruning that the average yield of the tree is so greatly reduced as to render the practice unprofitable. Probably with some varieties with which the tendency toward alternate bearing is not strong an excessive amount of pruning would not be necessary; while with some perhaps if enough fruiting wood is left for even a fair crop alternate bearing will not be prevented. Thus, in the Cornell University orchard vigorous healthy trees of some varieties began to bear alternate crops while they were but seven and eight years old; and the pruning, discussed in this chapter, which rather strikingly reduced the average annual yield, did not prevent alternate bearing; although these trees were in a retentive soil and had an abundance of nitrogen supplied.

If one is willing to reduce the fruitfulness, one may to some extent, by severe pruning, replace cultivation and fertilization. Thus, if the soil is low in nitrates and water, one may increase the supply of both to the part of the top left after pruning, since, temporarily, the absorbing system is not reduced as the top has been by the pruning. There is, therefore, less top to be supplied for the same absorbing system. Of course, the effect of any one pruning is only temporary. It must be done every year to maintain the tree at a vigor above what it would have without the pruning. The reduction in the size of the top, and therefore in bearing possibility, would be great, probably always so great that the loss of fruit would be much greater than the cost of adequate cultivation and fertilization. In the case of trees growing in a lawn, however, sod is unavoidable; and it may be desirable to have the tree kept small. This principle may then be used; and one may have the tree larger by use of nitrogen and little pruning, or smaller by use of more pruning and little or no nitrogen. The tendency of the tree to bear might be the same, but the bearing surface would be greater with the tree having nitrate and little pruning.

It should be emphasized that under some special conditions trees that have reached full bearing ages may not always be reduced in growing surface by moderate pruning, particularly by well distributed cutting back of the ends of the branches, even when the total weight of fruit borne is not reduced. With old trees under some conditions there are many more blossoms than enough to set a desirable crop of fruit. In California, particularly, the bloom tends to be exceptionally heavy; and weather conditions seem generally to be favorable for the setting of very large crops, much thinning often being necessary. With some kinds at least, the blooming and setting of these surplus fruits seriously checks growth, the leaves being small and the new shoots short, unless much cutting back is practiced. If the wood cut away in pruning contains very large numbers of fruit buds, the dwarfing effect of the pruning may not be greater than would be the dwarfing effect of the opening of those buds and the setting of fruits to be thinned off. But we do not have the results of any careful study as to the dwarfing effect to be expected from pruning trees in such a bearing condition. However, we can be certain that with such trees, whether it reduces their growth or not, a considerable amount of cutting back may be necessary in order to cause the fruit to be of desirable size. Removing excess fruit buds in pruning is much more effective in increasing the size of the fruit left than is thinning after the fruit has passed the "June drop."

The most striking invigoration by pruning that I have observed has been in the orchards where the water supply was limited. Thus, in old pear and plum orchards of California in which irrigation is not practiced, on trees with which the branches are not cut back the leaves are of a pale green color and almost no length growth is made; while on trees having the twigs cut back annually to stubs six or eight inches long or shorter the foliage may be deep green, in striking contrast with that of adjacent unpruned trees, and shoot growth may be strong. As to whether this results in largest part from the cutting away of fruit buds and prevention of excessive bloom, from the bringing about of a more favorable carbohydrate-nitrogen relation, from an improved water supply due to removal of resistance to water movement or merely from a reduction in the demand for water we have the results of no study. However, adding water to the soil will often cause a good growth to be made by the unpruned trees; and young trees that have not yet developed a large transpiring leaf surface make good growth in such sections without pruning or irrigation. Thus it seems certain that lack of water may cause the condition that pruning will correct, whether pruning exerts its invigorating effect alone through its reducing the transpiring leaf surface or in part through that influence and in part through some of the other possible influences mentioned.

Summary. Pruning, particularly cutting back a tree, causes an increased vigor of top growth, the leaves being larger and greener and length growth continuing later in the growing season. A part of the apparent increase in vigor is due merely to the fact that the advantage possessed by end buds and buds near the end is given to buds the growth from which would normally be rather weak because of the position rather far back from the end. A part is also certainly due to the fact that by pruning the transpiring leaf surface is reduced and the water supply to the parts left is thus improved. A part may also be due to other influences such as reduction in the amount of growing surface and consequently an improvement in the nitrogen supply to the part left; a reduction in carbohydrates in relation to nitrogen; an improvement in the efficiency of the wood in conducting water or nitrogen or both. With trees bearing fruit buds to the ends of the twigs a large part of the invigorating effect of pruning is due to the cutting away of fruit buds and the consequent prevention of both excessive blooming and the setting of excessive crops of fruit.

In spite of the invigorating effects pruning is a dwarfing process, the size of the tree generally being reduced by the amount of wood cut away and in addition by the reduction in growth caused by the reduced leaf surface. Generally as trees grow older pruning reduces root growth more than top growth. Under most conditions pruning seems to reduce total growth as much as it reduces the leaf surface; and under some conditions it reduces it more, a given leaf area leaving in the trees less dry matter than is left by the same leaf area of unpruned trees. Pruning generally reduces the amount of fruit borne by young trees more than it reduces the size of the tree; and under some conditions the dwarfing effect of the extra amount of fruit borne by the unpruned tree may be as great as the dwarfing effect of moderate pruning. Pruning may be severe enough to cause the development of a vegetative condition unfavorable for fruit-bud formation. However, except with trees so young that they have not begun to bear appreciable crops, such pruning is seldom practiced; and pruning may greatly reduce the crop of young trees merely by reducing the bearing surface, both the pruned and the unpruned tree being highly fruitful but the pruned tree being the smaller. The invigorating effect of pruning is much more striking with old trees and with trees growing where the supply of water or of nitrogen or of both is low, than with young trees having an adequate supply of water and nitrogen. Pruning an old tree before blooming time may cause a larger percentage of the flowers to set fruit, and seems to reduce the tendency of the tree to bear in alternate years. As to whether or not these conditions can generally be accomplished except by means of such severe pruning that the average annual crop is unprofitably reduced we have little evidence.

CHAPTER 16

RESPONSE OF FRUIT TREES TO PRUNING AT DIFFERENT SEASONS

The effect on the tree of the removal of wood is influenced by the time in the year when the removal is done and there is much discussion in horticultural literature as to the best season for pruning. The greatest differences in response should be found when the effect of pruning in the dormant season is compared with that of pruning during the growing season.

Summer Pruning and Dormant Pruning

Effect on growth. The immediate response to summer pruning is influenced by the state of growth when the cutting is done. Thus if pruning is done early in the summer there will generally be a response in new growth that is something like the response to pruning during the dormant season. New shoots growing from near where the cut was made (when the pruning is a cutting back of twigs or branches) will be somewhat more vigorous in appearance than on similar unpruned trees. The leaves will generally be slightly larger, though because they are younger the green color may, for a brief time, be less intense than on unpruned trees. Both Gardner (812) and Blake (768) have shown that growth will continue later in the season. Blake has shown that, with peach trees at least, not only is the wood delayed in maturity, but even the fruit ripens later on trees that have been pruned rather severely in early summer.

The immediate response to pruning in late summer may be different. If the tree has ceased length growth long enough before the pruning for it to be in its rest period, there may be no evident response to pruning until the following spring, when the new growth may show increased vigor similar to that shown when the pruning is done in the dormant season though not as great. It is hard to learn when the tree is sufficiently in the rest period for no new growth to result. Sometimes for a considerable period after length growth has ceased slight new growth will result at the end of the branch that is cut back; and with Wagener apple I have occasionally observed this new growth to be terminated by a cluster of flowers. (As Magness (230) has suggested, this bloom may have been from a bud in which flower parts development had begun before the pruning was done.) Since pruning at this time removes much foliage, we should expect a reduction in the amount of carbohydrates formed, and therefore a reduction in the root growth, as well as a reduction in storage of organic materials. For this reason we should not expect as greatly increased vigor of growth during the following spring as if the pruning had been done during the dormant season.

When a large amount of pruning is done early enough in summer to cause later growth than results from dormant pruning, the effect on the hardening of the wood will be determined to a large extent by the length of season and the abundance of water supply during late summer. In the lower latitudes in which deciduous fruits are grown, rather heavy early summer pruning would probably affect the trees much as would dormant pruning in so far as the nature of the wood is concerned. It should harden well and probably set fruit buds as well as if the pruning were in the dormant season. Of course, the sunnier and drier the weather or the less retentive the soil, the higher the latitude in which the section may be and yet have the wood harden well after such severe early summer pruning. In the higher latitudes, however, especially where the water supply is abundant, rather severe summer pruning before the trees had gone into the rest period — and thus ceased to make renewed growth in response to pruning — might, as Gardner (812) has suggested, cause the trees to grow so late that parts of the wood might not be sufficiently hardened to enable it to endure the winter. In the highest latitudes in which deciduous fruit is grown this would generally happen.

Pruning after the rest period has begun also should delay maturity. For while it will not stimulate new growth during the same season, it will reduce the leaf surface, and a large leaf surface is necessary for the hardening of the wood. In fact, it is probable that such pruning may reduce the hardiness of the tree more than will early summer pruning.

The effect of summer pruning on the amount of wood growth should be to reduce it slightly more than it is reduced by dormant pruning. Not only is the wood containing buds that would be leaves the following year removed, but in addition large numbers of the current season's leaves are removed before they have made their contribution in photosynthesis. Summer pruning, then, whether early or late, should be more of a dwarfing process than winter pruning. Again, however, the length of the season may influence the amount of this dwarfing effect. If the season is very long and hot the leaves on the new growth that follows early summer pruning may be ready to fall by the time they are killed off by autumn freezes. And, in the case of late summer pruning, the leaves may have nearly reached the end of their productive life before they are pruned off. Their removal under such conditions should be only slightly more of a dwarfing process than if they were permitted to fall and the same amount of pruning were done the following spring. Summer pruning then should be more of a dwarfing process in high latitudes, where the seasons are short, and in humid regions and regions where the sky is generally hazy than in lower latitudes or in dry and sunny regions.

While, theoretically, summer pruning should be more of a dwarfing process than winter pruning, it is not easy to determine, experimentally, whether in actual practice such is the case. For it is not easy to determine when one is doing equally severe pruning in summer and in winter. The experimental evidence is therefore not very conclusive. Pickering (872) working with a number of fruits and Alderman and Auchter (20) working with apples seemed to find summer pruning to cause a greater dwarfing effect than dormant pruning. Tufts (903) seemed to find in California a much greater dwarfing effect from pruning apricots, cherries, and pears in midsummer than in early summer. Alderman and Auchter also seemed to find midsummer pruning to dwarf more than did early summer pruning. However, as to early summer pruning and midsummer pruning the differences as published by Alderman and Auchter seem rather small and Tufts does not make it clear whether or not the severity of pruning was the same with trees pruned dormant, those pruned in early summer and those pruned in midsummer.

With some peach trees at Cornell University early summer pruning caused a greater dwarfing effect than dormant pruning caused. However, the trees pruned in early summer were cut back to the same level to which the dormant pruned trees had been cut; and so the summer pruning was more severe than the dormant pruning by the amount of growth made in spring before the summer pruning was done. In another experiment at Cornell University, with some young apple trees the second summer in the orchard, pruning in summer during one season reduced root growth much more than it was reduced by dormant pruning of about the same degree of severity. At the end of the growing season the average weight of the roots of the trees pruned dormant was 14.3 ounces while that for trees pruned in early summer was 9.5 ounces. In the spring of 1919 in still another experiment at that institution a special effort was made to have the severity of pruning the same for trees pruned dormant and those pruned in early summer; that is to have the amount of wood removed in early summer enough greater than the amount removed in dormant pruning in the preceding spring, that the percentage of the top cut away would be the same for the dormant and the early summer pruning. It was assumed that the new growth from the average twig would be in the same proportion to the new growth from the remainder of the tree that the twigs were to the remainder of the tree before growth started. Accordingly whole twigs were removed in the spring pruning and whole twigs with the new shoots from them in the early summer pruning.

The trees were Northern Spy apple, three years from the graft, and were paired, trees with an equal amount of 1918 twig growth being compared with each other. There were twenty such pairs. On one tree of each pair half of the 1918 twig growth was removed while dormant, the twigs removed being evenly distributed among upper and lower branches so that twigs representing an average for the entire tree would be removed. On the other tree of the pair twigs were selected in the same way and marked. These marked twigs with the shoots that had started from them were removed in early summer, July 9th. Much leaf surface was of course removed in the summer pruning, the reduction being from an average of 2195 square inches of leaf surface to the tree to 1143 square inches. On September 20th, the leaf surface of the average dormant pruned tree was 1895, and of the average summer pruned tree 1265 square inches. The reduction in top growth was slight, if there was any. For, on account of exceptionally dry weather, very little growth was made by any of the trees after the time of summer pruning. The average root weight of the dormant pruned trees was 0.83 pounds and that of the summer pruned trees was 0.68 pounds. Each pair of trees was compared as to percentage gain or loss in root weight due to summer pruning and the average was a loss of 13.97±4.25 per cent. It seems reasonably certain that the difference in root weight was due to a reduction in growth caused by doing the pruning in summer. It should be emphasized that these roots had been growing three years when the experiment was begun and that during this fourth summer with the dormant pruned trees there was a reduction in leaf surface due to pruning while with the summer pruned trees the leaf surface was not reduced until the pruning on July 9th. On that date the average leaf surface of the summer pruned trees was 2195 square inches as against 2082 square inches for the average dormant pruned tree. The reduction in root growth, then, all came after July 9th, of the fourth summer, when, due to the pruning, the average leaf surface dropped to 1143 square inches; the supply of organic nutrients being reduced and a slight new shoot growth that would use organic nutrients being stimulated.

It seems probable that this method of pairing gave as nearly equal severity of pruning as would be given by any method that could be devised for comparing dormant pruning with pruning in summer done before length growth has ceased. The effect of pruning in late summer after length growth has ceased can be more accurately compared with that of dormant pruning. For, if the late summer pruning is done in the season preceding the dormant pruning, the trees will be of the same size when pruned. With late summer pruning the effect of cutting back could be studied as accurately as the effect of cutting out branches; for the shoots would have reached their full length and could be cut back just as far as the twigs on the dormant pruned trees would be cut in the next spring. It would be expected that the increase in dwarfing effect of summer pruning over that of dormant pruning would be greater in cutting back than in thinning out whole branches; for, in summer cutting back the larger better lighted leaves are the ones removed in largest numbers. Of course, if one is cutting back the twigs of a branch in order to reduce the size of that branch relative to the remainder of the tree, one can make the summer pruning enough lighter than the dormant pruning to accomplish only the same amount of dwarfing. In other words, in shaping young trees one can avoid the greater dwarfing effect of summer pruning by doing lighter pruning.

With trees that bloom heavily to the ends of the branches, pruning in early summer after the fruit has reached considerable size should be much more of a dwarfing process than dormant pruning and more than pruning in late summer after the fruit has matured. Dormant pruning and late summer pruning by removing many fruit buds would reduce the depleting effect caused, in the summer following, by the development of an excessive bloom and an excessive number of fruits; while with early summer pruning there would be the combined dwarfing effect of the pruning and the setting of an excessive crop. In some sections with short growing seasons, the early summer pruning might reduce the tendency for fruit buds to form at the ends of the new shoots, those which grow after pruning; but in other sections with growing seasons more favorable for fruit-bud formation that might not be true.

It should be emphasized also that, while under conditions generally prevailing, pruning in summer seems to reduce growth more than it is reduced by an equal amount of dormant pruning; under some conditions there might develop in the tissue a chemical condition such as excessive accumulation of total carbohydrates or excessive accumulation of some specific organic compound that might inhibit growth. Perhaps under such conditions pruning, by reducing the leaf surface and, therefore, the supply of organic substances, might bring about in the tissue a chemical condition more favorable for growth. Yet it seems very doubtful if, without a more permanent environmental improvement — perhaps an increased soil water or nitrogen supply — such a favorable chemical condition could last long enough to cause an increase in growth equal to the amount of wood removed in pruning. For, unless there were such improved soil conditions, before there could be a very large gain in growth the increased leaf surface would probably have brought about, again, the accumulation of inhibiting organic substances. It seems probable also that since most of this tree growth is made early in the season, such an improvement in the vegetative condition of the tissue would be more effective if brought about by dormant pruning. Yet such an influence from dormant pruning seldom if ever lasts long enough to cause an increased growth great enough to offset the wood removed in pruning. In fact, pruning at any time generally reduces total growth.

Effect on fruiting. The statement is often found in literature that summer pruning encourages fruitfulness by checking wood growth. Thus Waugh (916) says: "Winter pruning has a tendency to promote wood growth. . . . Summer pruning has a tendency to promote the formation of fruit buds and to check wood growth." Many of the older writers like Hovey, and some European writers, recommend summer pruning as a means of encouraging fruit-bud formation. These writers have in mind trees that are pruned to forms like espalier work, where very much pruning is done, and the summer pruning recommended is nearly always a pinching off of the ends of the young shoots at various times during the summer. And it may be that such pinching encourages fruit-bud formation by some other means than merely a checking of wood growth; or it may be the desire of the worker not necessarily to increase the tendency of the whole tree or branch to form fruit buds, but rather to bring about a local influence favorable to fruit-bud formation at given points.

We have seen that summer pruning done early in the season does not hasten the ending of wood growth, but rather promotes a later growth; and of course summer pruning after wood growth has ceased cannot be said to check wood growth. Increased fruit-bud formation is not generally associated with delayed maturity of the wood. Further, we have seen that summer pruning seems to dwarf the tree slightly more than dormant pruning; and so even if summer pruning should increase the tendency to set fruit buds, since it reduces the size of the tree, it might not increase the amount of fruit borne. Thus even if summer pruning should increase the percentage of buds to become fruit buds, since it reduces the number of buds on the tree, it might not increase the total number of fruit buds on the tree. In fact, even if the total number of fruit buds on the tree were increased the total yield might not be; for, the grower seems generally to have a greater problem in the failure of the blossom to set fruit and in the failure of the fruit to reach the best marketable size than in the failure of the tree to set fruit buds. And if a tree of reduced size were caused to set an increased number of fruit buds, the tendency would be either for a smaller percentage of the flowers to set fruit or for an excessive number of small fruits to be borne.

With kinds the fruit buds of which are formed on the spurs, the effect of cutting back the shoots in early summer when such cutting stimulates new growth seems to be to increase the percentage of buds to form spurs on the previous season's wood and on the current season's wood. Thus, Gardner (812) seemed to find an appreciably larger percentage of such spurs on trees that had been both summer and winter pruned than on trees that had been winter pruned only. It would seem possible that, while in Oregon the summer pruning thus encouraged the formation of spurs, in some more humid climate it might encourage the pushing of those buds into shoots instead. Magness (230) could find very little influence exerted by summer pruning on fruit-bud formation on spurs that had already formed. However, buds on shoots formed after summer pruning gave a larger percentage of spurs than buds on shoots of unpruned trees. In the case of varieties that form axillary fruit buds, he found that summer cutting back tended greatly to reduce the number of such fruit buds formed. It would seem probable that the nature of the soil and the length and nature of the growing season would have much to do with the formation of axillary fruit buds on the new wood that follows early summer pruning. Thus in a short growing season we should expect such early summer pruning very greatly to reduce or to prevent the formation of axillary fruit buds on such new wood. On the other hand, in sections where the summers are long and hot, and particularly if the water supply is limited, it does not seem improbable that many axillary fruit buds may form on this new wood following early summer pruning. Thus, Keffer (844) working in Tennessee found many fruit buds on new shoots that grew on peach trees after they had been pruned in early June. In fact it does not seem impossible that in the case of a tree in soil where both nitrogen and water supply is limited, and where the summer is rather long and hot, the reduction in foliage resulting from early summer pruning, which would result in an increased supply of water and probably nitrogen to what is left, might actually increase the number of both axillary and spur buds formed. I know of no experimental evidence obtained under such conditions, however.

When summer pinching-off of the end or cutting-back of a shoot stimulates fruit-bud formation, it generally seems to affect only the buds near the point where the cut is made. While there is little careful experimental data concerning the subject, there is certainly enough of the results of experience to justify the conclusion that if such pinching or cutting is done at the right time, it may stimulate the formation of more fruit buds near the end of each shoot. If the pinching is done too early, shoots will grow instead. Thus, Wakely (914) says, "The apple has a greater tendency to secondary growth than the plum. Hence it is absolutely useless to give any general direction for summer pruning." Hovey (832) recommends such summer pinching in the month of July, but says, "There is no fixed time for performing the operation." Apparently only by continuous attention and perhaps by repeated cutting or pinching can one be certain of doing the work at the right time to stimulate fruit-bud formation as desired. How such fruit-bud formation is stimulated, whether merely by the accumulation of carbohydrates just back of the pinched or cut end, or by the bringing about of a favorable carbohydrate-nitrogen relation, or through some other chemical influence, we do not know. Both because of the great expense of doing the work and because of the great reduction in growth of the tree such summer pinching or cutting seems to have little promise for American orchardists.

As to the effect of giving the pruning necessary to train a tree in summer rather than while dormant, Pickering (872) seemed to find that summer pruning reduced the fruitfulness rather more than an equal amount of dormant pruning. In this case the pruning was largely a cutting-back.

In a later experiment Pickering (757) found fruiting greater the later in the growing season the pruning was done. Considering the fruiting of dormant pruned trees as 100, that for trees pruned in July 15th was 113; for trees pruned August 15th, 124; and for trees pruned September 1st, 141. However, that for unpruned trees was 180; and the less severe the summer pruning the larger was the crop. It seems, therefore, that summer pruning has not stimulated fruiting but has caused less reduction than has dormant pruning. Since the trees used were young ones that were increasing in size rapidly, those pruned in summer were larger when pruned than were the dormant pruned trees in the previous spring; and, unless the amount of wood removed was increased accordingly, summer pruning was relatively the less severe.

Alderman and Auchter (20) found a greater reduction in fruitfulness in young apple trees through summer pruning than through dormant pruning. Both the summer and dormant pruning consisted of some thinning out of the shoots or twigs and of cutting back; removing annually about one fourth of the length of the shoot or twig.

Gardner (812) found considerably more fruit spurs formed on trees that were pruned during the dormant season and again rather severely in early summer than on trees that were pruned during the dormant season only. They did not form so many fruit buds, however, as did unpruned trees. His results agree with those of Magness in that he seemed to find that when the pruning was done in summer, with young trees, a larger percentage of the buds on the wood back of the point where a shoot was cut off formed spurs. He suggests that the increase in the number of fruit spurs is due largely to the fact that buds on the new shoots that grow after the early summer pruning very readily push into spurs in the following year. It is possible, however, that more buds were left on the trees which had summer pruning. It is not possible to know what happened unless all the buds left are accounted for. Harvey (826), who continued the experiment, seemed to find that as the trees grew older they showed both growth and fruitfulness to have been reduced more by summer than by dormant pruning.

Batchelor and Goodspeed (756) published the results of some pruning experiments in which the summer pruning consisted of a removal of the suckers and thinning-out of the dense growth of the tree. The summer pruning was always in addition to the dormant pruning. From what has been said we should not expect the mere thinning-out of wood in summer to stimulate the formation of fruit buds; and, since the trees were young, if a considerable amount of wood were removed we should expect it, on account of the removal of buds, actually to reduce the numbers of fruit buds. And in their work summer pruning seemed to have that effect. The crops during the first four years of bearing were smaller, though the differences were not great. Decidedly the largest yield was on unpruned trees. Vincent (913) has published the results of an experiment to test the relative value of summer and winter pruning of apple trees for the conditions and cultural methods of Idaho. There were but two plots containing five trees each of Jonathan, Rome Beauty, Grimes Golden, and Wagener. Certainly the summer pruning resulted in a better color of the fruit. This would be expected, since by the summer pruning the trees could be opened out to the light at the time when light is most needed for the development of color in apples. Specific studies of fruit-bud formation were not made, but Vincent published the yield for each tree of each plot during the first seven years of bearing, and concluded that in case of each variety summer pruning had increased the yield. However, the difference is not great and the probable errors are large enough for the differences to seem significant in case of only one variety as Table 56 suggests.

Evidently there was no measurable difference in yield between the summer and winter pruned trees, except in the case of Wagener. With

TABLE 56. EFFECT OF SUMMER PRUNING ON YIELD OF APPLES

VARIETY	TOTAL AVERAGE YIELD 1910–16		DIFFERENCE
	Pruned late summer (lbs.)	Dormant pruned (lbs.)	
Jonathan	870.9	834.7	36.2±77.2
Rome Beauty	450.8	391.6	59.2±74.0
Grimes Golden	738.4	689.0	49.4±59.2
Wagener	689.4	402.5	286.9±30.8

that variety the difference between the yields of the summer and winter pruned plots was much greater than the probable error. The difference, too, seems to have resulted from the difference in pruning methods, and not from soil differences. Thus, in one row the total yields to the tree from 1910 to 1916 were 830, 699, 755, 990, 860, 495, 566, 303, 435, 271 pounds, and in the other, 437, 583, 841, 524, 668, 431, 337, 314, 351. In each case the first five are the summer-pruned trees. In both rows there is a sudden drop when the winter-pruned trees are reached. While it is possible that throughout the summer-pruned plot the soil conditions were more favorable for the fruiting of trees than in the dormant-pruned plot, it seems probable that the difference in yield was due to the pruning. That is, pruning the trees in summer instead of while dormant caused a better yield with Wagener trees, though it did not measurably influence the yield with the other varieties. How has this increased yield been brought about? It seems certain that the summer pruning has not increased fruitfulness in the way that ringing would increase it — that is, by causing an increased concentration of carbohydrates; for summer pruning, by cutting away foliage, should reduce the supply of carbohydrates; and trees of the Wagener variety generally set so many fruit buds in each alternate year that their being stimulated to set more would not increase the yield. If summer pruning should, by reducing the supply of carbohydrates and by causing a temporary check in growth, increase the supply of nitrogen relative to carbohydrates, it might possibly reduce the tendency to form an excessive number of fruit buds in alternate years. It might then be expected to reduce the tendency toward alternate bearing. However, in this experiment the tendency toward alternate bearing was as marked with the summer-pruned as with the dormant-pruned trees. The greater yield of the summer-pruned trees was more striking in the years of the heavy crop except in the last year of the experiment. Weights or measurements of the prunings removed were recorded for only the last two years. If less wood was removed in the summer pruning the trees might be expected to bear more fruit. Without more information concerning the amount of the pruning and perhaps more data concerning specific responses such as the amount of twig terminal and axillary bloom and the percentage of the flowers setting fruit, it does not seem to be possible to determine how the summer pruning increased the yield of these Wagener trees — if the greater yield was due to the summer pruning.

Drinkard (806, 807) did some work with summer pruning of dwarf apple trees that were five years old at the beginning of the experiment. He pruned plots of four trees each, on April 23d, June 23d, and November 23d, 1913. The pruning consisted of a thinning-out and some cutting back. The April pruning differed from the June and November pruning in that the cutting-back consisted of the cutting-away of a large part of the 1912 wood, while in the June and November pruning it was the 1913 wood that was largely cut away. The possible number of fruit spurs that could form on the trees during the next two or three years was, therefore, larger on the summer and autumn pruned trees; for the spurs that would form in 1913 and, on trees of this age, be responsible for part of the bloom of 1914 would be on twigs of 1912. In this experiment it is only by comparing the summer-pruned trees with those pruned in autumn that any information as to the relative effect of summer and dormant pruning can be obtained. For, since length growth had about ceased when the summer pruning was done, a given amount of wood cut away at that time would represent approximately the same percentage of the whole top as if the same amount of wood were cut away in autumn of the same season or in the spring following. There seemed to be no significant difference between the number of fruit buds formed on the summer-pruned and that on the autumn-pruned trees.

Palmer (868, 869) reports an experiment with dormant and August pruning of apple trees in the province of Ontario, Canada. One plot had no pruning, one was pruned in the dormant season, and one in August. The dormant and August pruned plots, however, were not comparable, since those pruned in the dormant season were pruned very severely, while those pruned in August were pruned very lightly. Trees receiving dormant pruning yielded much less than those receiving summer pruning, but those with summer pruning yielded only about half as much as those receiving no pruning. Thus summer pruning has not stimulated fruitfulness. Rather, both dormant and summer pruning reduced it, the greater amount of pruning causing the greater reduction. The results give no information as to what would be the relative effect on fruitfulness of equal amounts of dormant and summer pruning.

At the Cornell Experiment Station apple, pear, and plum trees were, for a number of years, kept under experiment as to the effect of summer pruning on fruitfulness. With the plums and with the pears, there were five rows of twenty trees each, ten trees at one end being pruned in early summer (usually July) and ten at the other end pruned while dormant. With apples, there were ten rows of varying lengths, the average being fourteen trees long; the trees in the south half of each row being pruned while dormant and those in the north half being pruned in midsummer. Thus many of the trees in one plot were so far from those in the other that rather marked soil variations were introduced. Small differences in yield or in the number of flowers borne would, therefore, not be significant. Summer pruning of these apple, pear, and plum trees caused no stimulation of earlier fruitfulness that could be detected under the conditions of the experiment. Most of the pruning was a clipping-back of shoots, the kind of summer pruning which next to repeated pinching off of the growing point seems most likely to stimulate fruit-bud formation. In another experiment with apples, twenty trees in one row received dormant pruning, and twenty in an adjacent row received summer pruning. In each case the pruning was what was necessary to give an open head with five branches, the upper one being the largest and the secondary branches of each being pruned back so that each main branch would have a central leader. There was thus a considerable amount of pruning and many twigs or shoots were shortened back. In Table 57 is shown the average weight of prunings to the tree with each variety — the leaves being pulled from the summer prunings before the weighings — and the yield by the time the trees were ten years old.

Since most of the annual growth was made by the time of the summer pruning, the tree tops were nearly a year's growth larger when the summer pruning was done each year than when the dormant pruning was done; and so the amount of pruning relative to the size of the tops certainly was not the greater with the summer-pruned trees. The land sloped downward toward the north where the soil was better and the trees tended to grow better the farther down the slope they were located. The summer-pruned trees were the farther down the slope and with like treatment would have unquestionably grown faster and yielded more

TABLE 57. COMPARISON OF THE INFLUENCE ON FRUITFULNESS OF SUMMER AND DORMANT PRUNING

VARIETY	NUMBER OF TREES PRUNED EACH WAY	TOTAL WEIGHT (IN POUNDS) OF YOUNG WOOD REMOVED IN PRUNING (AVERAGE TO THE TREE AT THE END OF TEN YEARS)		TOTAL AVERAGE YIELD (IN POUNDS) TO THE TREE AT THE END OF TEN YEARS	
		Dormant pruning	Summer pruning	Dormant pruning	Summer pruning
Baldwin	3	13.1	14.8	263.4	250.1
McIntosh	2	10.2	6.2	538.9	513.3
Northern Spy	2	10.1	15.5	52.5	125.9
Oldenburg	2	3.6	3.9	343.1	235.2
Rhode Island Greening	2	7.7	17.2	621.4	708.7
Tompkins King	2	8.2	10.3	118.8	117.9
Twenty Ounce	2	17.4	8.3	431.1	381.9
Wagener	1	7.0	5.4	518.8	450.2
Wealthy	2	6.7	5.7	521.6	548.4
Average by variety		9.3	9.7	378.8	370.2

than the trees in the row that received dormant pruning. Thus, the unpruned trees in the row next below the summer-pruned row were much larger and yielded much more than the unpruned trees in the row next above the dormant-pruned row. It is reasonably certain then that a kind of midsummer pruning which has included a considerable amount of cutting-back of shoots has not only failed to increase fruitfulness but rather has caused some reduction in fruitfulness of these young apple trees.

Howe (834), working in New York, did not find thinning out of the branches of young apple trees in July and August measurably to influence the yield as compared with the yields of trees pruned similarly in the dormant season. He called attention to a disadvantage of summer pruning that is generally experienced. While the trees are young enough not to bear it is convenient to do the work in summer; but after bearing begins it is very inconvenient, much of the fruit being knocked off.

Ravaz (877, 878), working with *Vitis vinifera* in French vineyards, found summer pruning to reduce the yield by weakening the vines. Thus the average weight of clusters during twelve years, on the vines pruned just after the fruit was picked, was 2.188 kg., while the average for vines pruned after the leaves fell was 2.978 kg.; and the average shoot weight on vines pruned after the fruit was picked was .4968 kg., while the average on vines pruned after the leaves fell was .6746 kg. These grapes were pruned to a definite form, certain amounts of new wood being left each year. We can be certain then that the pruning was uniform except as to time. The reduced growth and fruitfulness has plainly resulted from the fact that the leaves were removed before they had made their full contribution to the plants. It seems highly probable that results similar to this, though perhaps much less in extent, must follow any summer pruning of mature plants bearing a crop of fruit. It is difficult to detect the effect with other fruit crops because the pruning is much less extensive and because it is so difficult to determine with certainty whether or not the summer and dormant pruning have been equally severe. However, in California, in some orchards, continuous midsummer pruning seems to have lowered the vigor of the trees strikingly enough to be detected without experimental methods.

Summer pruning in different environments. We have seen that the immediate response to summer pruning is influenced by the time in summer when the pruning is done, and that Alderman and Auchter (20) and Tufts (903) seemed to find midsummer pruning to dwarf young trees more than early summer pruning. It seems probable that the time in summer when the pruning is done may very greatly influence the extent of the dwarfing effect; and while we have little applicable experimental data, it seems wise to discuss some feature of the problem from the standpoint of what very incomplete physiological knowledge might lead one to think would be the response. It would be expected that in addition to the influence of the season of pruning, the response to summer pruning might be influenced by the condition of the tree as to fruit-bud formation (that is, whether or not the tree was in a condition such that the pruning would prevent an excessive bloom); and by whether or not the water supply in late summer was large enough for normal root growth after the time when the pruning was done.

It seems probable that with a water supply in late summer large enough for root growth to continue until late autumn or winter, the greatest dwarfing effect would result from pruning just late enough in summer that little or no new growth would be made. For, during the remainder of the season not only would there be no new top growth made, but, because of the greatly reduced leaf surface, root growth, storage of organic materials, or both should be greatly reduced. If the pruning were done earlier in the summer the new growth made would bear new leaves; the earlier the pruning the greater the amount of new leaf surface that would follow the pruning. And, of course, the later the pruning after midsummer the shorter would be the time in which the tree would have a reduced leaf surface and therefore, the less would be the reduction in root growth and the nearer would the invigorating effect approach that following dormant pruning. In other words, it seems that the dwarfing effect of summer pruning should be reduced in proportion as the pruning is done earlier or later than midsummer. And the invigorating effect — immediately following in the case of early summer pruning and showing in the following spring in the case of late summer pruning — should be reduced as the time of pruning approaches midsummer either from early spring or from late autumn. In fact, while in the spring following late summer pruning there is generally increased vigor of growth as a result of the pruning, it does not seem impossible that with midsummer pruning the reduction in leaf surface lasting so long might have caused such a reduction in root growth that by the following spring the root system would be no greater relatively to the demands of the top than it would have been if no pruning had been done; and the vigor of the new growth no greater. Of course, if twigs were cut back in midsummer the growth from the buds left at the end of the stubs would be greater than it would have been from those same buds if the growth beyond them had not been cut off. This merely because they would be given the advantageous position of end buds.

If, however, the tree should be in such a condition that midsummer pruning would prevent excessive fruit-bud formation and the dwarfing effect that, in the following spring, would result from the heavy bloom, then, even though the amount of fruit borne might not be reduced, the dwarfing effect might be no greater than if the pruning had been done nearer to spring or autumn; and if midsummer pruning should reduce the amount of fruit borne either in the season of the pruning or from the bloom of the following spring the reduction in vigor of the following spring's growth might not be marked — the effect on wood growth of doing the pruning in midsummer being offset by the effect on wood growth of a reduced crop.

Fruit may be grown where there is only winter rainfall or where irrigation water is available only in winter and early spring. Under such conditions the water supply in some soils might become so low in late summer that there could be little root growth at that time. It would seem doubtful if in such situations pruning in late summer would cause the vigor of growth in the following spring to be much less than would follow equally severe dormant pruning. Further, if the water supply should be inadequate for satisfactory ripening of the fruit a reduction in spring vigor of growth might be desirable to avoid excessive loss of water; and since the water is quickly depleted in the part of the soil into which the roots have penetrated thickly, it might be important to keep the roots from penetrating all the soil until as late as possible in the life of the orchard, in order that there might be reserve soil into which they could be growing and obtaining enough water to ripen the fruit normally. Even with the much weakened growth resulting from midsummer pruning, there might be better development of the fruit; though, of course, there would be less fruit to the acre than would be possible with an adequate water supply. Certainly in such dry sections, if summer pruning is rather generally practiced, one should have some definite experience in that situation or one nearly identical with it before recommending a different practice.

Pruning at different times in the dormant season. In this discussion, by "dormant season" is meant the period from leaf fall in autumn to blooming time or perhaps slightly later in spring. If we knew more about the movement and use of organic materials and possibly of some mineral nutrients, especially nitrogen, we might be able from that knowledge to determine when pruning would have the most desirable influence on the growth and fruiting of the tree or whether there is any time in the dormant season when pruning causes the most desirable response. Organic nutrients are being used in the process of respiration throughout the dormant season, and about blooming time large quantities are being used for growth. Further, there may be movement of these materials from one part of the tree to another. It is conceivable that the time of pruning might influence the supply of these materials either by influencing the amount used in respiration or by influencing the amount cut away in pruning. Thus if there is a movement of these materials outward from the roots, trunk, and main branches, pruning as soon as the leaves are off might tend to conserve organic nutrients, since the tissue would be removed in advance of such a movement of nutrients into it. If the storage materials remain throughout the dormant period about where they are when the leaves fall, the time of dormant pruning will have little influence on the reserve materials; for the materials will be removed with the branch anyway. If there is a movement of materials downward to trunk and roots, then the removal of a branch in autumn or early winter will remove material that would have gone downward to be left in the tree if the pruning had been delayed; and pruning early in the dormant season, by prolonging the exposure of unhealed wounds, may increase the consumption of reserves in respiration. It is certain that at leaf fall the concentration of total soluble materials in the bark is greatest in the twigs and is smaller downward, generally to the smallest roots. In Missouri at least (62) the concentrations in roots and top are more nearly equal by spring. As to whether this change results mainly from the movement from the tops to the roots of these soluble materials, or from a change of insoluble to soluble materials — this change being greater in the lower than in the upper part of the tree — I know of no conclusive data. In some sections with many warm days in winter there may possibly be a movement of substances downward after leaf fall until approximate equalization is reached and later a movement upward to replace what is lost by respiration, which should be more rapid in the top where the temperature would more often be high enough for rapid respiration. Thus from such considerations, it seems possible that pruning in autumn, in so far as its effect on the stored food supply is concerned, might be harmful in high latitudes and harmless or even beneficial in low latitudes or in sections where for other reasons there are many warm winter days. It is clear, however, that we do not possess enough fundamental knowledge to enable us, from such knowledge, to predict the effect on the tree of pruning done at any given time in the dormant season.

And there is very little evidence from actual experiments with pruning at different times during the dormant season. Pickering (872) gives the results of some demonstration experiments which indicate that for the climate of Great Britain if there are differences in the results to be obtained from pruning at different times during the dormant season such differences are not large enough to be measured by means of field experiments. Brierley (773) measured the growth in length and thickness of shoots following the cutting-back of twigs in each month from November to June. The May and June prunings, particularly that in June, seemed to reduce the growth of shoots; but the growth following pruning in any of the other months was about equally good. That is, pruning at one time in the dormant season seemed to give as good results as pruning at another. On the other hand Ravaz (877) found the earliest opening of the buds on grape vines pruned just after leaf fall. The opening on vines pruned in midwinter was about four days, that on vines pruned in early spring about six days and that on vines pruned after the terminal buds had started eleven days later. Pruning just after the crop was harvested delayed the starting of the buds about ten days. This suggests that pruning in fall or early winter causes the greatest invigorating influence, at least, with grapes.

The earlier starting of grape vines pruned early in the dormant season may have been due to an influence on the rest period. In California where most kinds of fruit trees are still partly in the rest when spring growth starts, Wickson (918) says vines or trees pruned early in the dormant season tend to start growth earlier than do those pruned later. Probably the pruning tends to hasten the ending of the rest period.

With tree fruits, in sections with winters long enough completely to break the rest period, every one who is in touch with many orchards has seen trees pruned throughout the dormant season, and has certainly been convinced that, in so far as the response of the tree is concerned, whatever differences there may be are so small that they could be measured only by the most careful experimental methods. Further, experience indicates that even severe pruning as late as when the trees are in full bloom does not obviously reduce the vigor or fruitfulness of the tree. We cannot say, however, that there are not differences in response which though too small to be detected except by very careful experimentation are yet large enough that it would be profitable to accept some inconvenience as to the use of labor in order to have the pruning done at just the right time for the most desirable influence on the growth and fruitfulness of the tree. It has been shown that cutting branches while dormant or just before the bloom opens may increase the percentage of flowers to set fruit. It does not seem impossible that if pruning at one time in the dormant season should invigorate the tree even slightly more than pruning at another time, that difference in vigor might occasionally be enough appreciably to influence the percentage of flowers setting fruit. However, if there is such an influence we have not discovered it and we do not know at what time in the dormant season pruning should be done in order to have the greatest invigorating effect, if there is any difference.

It is often said that in case of fall or early winter pruning there is danger of injurious water loss from the wounds. Thus, Bailey (750) suggests that in case of fall-planted trees it may be better to delay pruning until spring, in order to avoid water loss from the wounds. The amount of water loss from dormant wood, especially during cold weather, seems to be determined largely by the difference in temperature between the wood and the outside air. A higher temperature of the twigs results in an increased vapor tension within them, and therefore a tendency for the vapor to move outward; a twig temperature above that of the air often results from an absorption of heat by the dark pigments in the twigs. One would expect, then, that more water might be lost from the twig than from the small cut surface left when the twig is removed; and Howard, in some unpublished work, seemed to find this true. At any rate his data indicated strongly that, in the climate of Missouri in some years at least, fall planted trees will make an appreciably better growth during the first summer if they are pruned in the fall than if pruning is delayed until spring. In a climate such that there is less sunlight and where there are fewer days when the air temperature is rather high while the soil is frozen, the loss of water from twigs during winter would be so small that there would be no danger of injurious drying.

In sections where the winters may be extremely cold there is some danger of winter killing back of a fresh pruning wound; and in such sections it is wise to delay the pruning until early spring. However, under conditions where the winters are no colder than those of the fruit-growing areas of Western New York or Ohio, there is little danger and pruning may well be done at any time during the winter with all but the most tender varieties.

With the grape the effect of the season of pruning on the loss of sap from the wound ("bleeding") may be of some importance. Though experience suggests that, with *Vitis Labrusca* at least, such "bleeding" does not measurably influence the vigor of growth of the vines. With the common deciduous fruit trees such bleeding seems unimportant regardless of when the pruning is done. Thus in a study made at Cornell University branches were removed at intervals from early spring to June from trees of all the common fruit species; and in no case was there more than enough bleeding slightly to moisten the surface of the bark to a distance of a few inches below the wound. There may be seasons when more exudation will take place; but it is probably never enough to be of any practical importance.

Summary. Pruning done in early summer while the tree is still making shoot growth, or late enough in summer for all length growth to have ceased, under most conditions, causes an increased vigor of twig growth but to a less extent than with dormant pruning of the same severity. Pruning in midsummer may not increase vigor of growth. The increase in vigor of growth will show for early summer pruning during the season in which the pruning is done, but for late summer and sometimes for midsummer pruning not until the following season. With early summer pruning, and sometimes with midsummer pruning, shoot growth may be caused to continue later in summer than will the growth following dormant pruning; and maturity of both wood and fruit may be delayed if the summer pruning is severe. The reduction in root growth and, at least if followed through several years, in total growth seems to be a little greater with pruning any time in summer than with dormant pruning. And, although we have little or no dependable experimental evidence, it seems probable that pruning will cause the greatest reduction in growth if done about the time when — because the tree is going into the rest period — there will be but slight immediate growth response; for, by pruning at that time, the largest reduction in leaf surface should continue the longest. Cutting or pinching back shoots in summer may cause the formation of fruit buds just back of the cut ends; but summer pruning does not seem to increase the tendency to form fruit buds throughout the head of the tree. Pruning at any time in summer seems to reduce the amount of fruit borne by young trees a little more than it is reduced by equally severe dormant pruning, the greater reduction being probably due to the greater reduction in the size of the tree. The slightly greater dwarfing effect of summer pruning and the greater reduction of fruiting with young trees can probably be avoided by giving a little less pruning in summer than would be given in the dormant season. With fruits such as the apple and the peach, that require direct sunlight to develop good color, it is possible by pruning in summer, a short time before the fruit begins to develop red color, to expose more of the fruits to direct light and to cause a considerable increase in the percentage of fruits that become well colored. We have no data and no dependable physiological information as to whether or not summer pruning may ever be more effective than dormant pruning in adjusting the orchard to a low soil water supply. In sections where the winters are so mild that spring growth starts before the rest period is fully ended, pruning early in the dormant season may cause growth to start a little earlier in spring than it would start if the pruning were done later in the dormant season. In the coldest sections, pruning in autumn or early winter tends slightly to increase the susceptibility of the wood of some varieties of apples to injury from very severe freezing.

CHAPTER 17

SOME DETAILS OF PRUNING AND TRAINING

In the two previous chapters were discussed the responses of the tree to the cutting-away of parts either during the growing season or while the tree is dormant. This chapter will concern responses to detailed practices in pruning. No effort will be made to distinguish sharply between pruning done for its influence on growth or fruitfulness and that done to train the tree or plant to a given form. For pruning done to influence the bearing habit or growth of the tree must inevitably influence its form, and one cannot prune to influence the form without influencing also growth and fruitfulness. In other words, if, by cutting away of wood, a tree is trained to a form very different from that which it would naturally assume, its growth will be rather strikingly reduced. And although with old trees that are occupying all of the space available in the orchard fruitfulness might be increased in spite of a reduction in the size of the tree; with young trees profitable bearing will nearly always be delayed by any considerable amount of pruning. For, profitable bearing generally begins earlier the more rapidly the tree increases in size. This has been true not only in pruning experiments, but in practically all soil management experiments. Much has probably been lost by fruit growers due to their having adopted certain forms as being desirable without reference to the cost in delayed fruitfulness of getting such forms; and in any consideration of the training of the tree serious attention should be given to getting the desired condition with a minimum of pruning before the tree has reached a state when, for the best fruiting, more pruning is desirable. When such a state has been reached the pruning necessary to give desirable forms may often be done without causing such a dwarfing as to result in appreciable reduction in the yield of marketable fruit.

Cutting back and thinning out young trees. Bailey (750) says that cutting back branches tends to thicken the top of the tree by causing the growth of lateral buds or of dormant buds. Gardner (813) has studied the effect of cutting back apple twigs on the number and length of new shoots formed and on the percentage of buds to break. His evidence does not indicate strongly that an increased percentage of the buds break on the stub of a twig cut back while dormant to fifty per cent or less of its original length; and it is probable that little information can be obtained by merely counting the total number of buds on the branch parts left and thus determining the percentage to break. For, it is often true that a larger percentage of the buds toward the apex of a twig break; and even if cutting back such a twig should cause some buds on the basal half to grow that would otherwise remain dormant the percentage of buds to break on the stub left might not be greater than the percentage to break on an unpruned twig. Thus, let us assume that a twig contains sixty buds, seventy-five per cent of which will break if the twig is left unpruned. Let us assume, further, that if the twig is left unpruned twenty-seven of the thirty buds on the distal half of the twig, or ninety per cent, will break, and eighteen, or sixty per cent of the thirty buds on the basal half. Then let us assume that if the distal half of the twig with thirty buds is removed, it will cause three buds to break that would remain dormant if the twig were not pruned. The total number breaking then would be twenty-one, or seventy per cent. Although twenty-five per cent of the buds on this basal half that would have remained dormant, but for the pruning, will have been caused to break, yet the percentage of buds to break will be smaller than would have been the percentage to break on the whole twig unpruned. This source of error could probably have been eliminated if the location of the dormant buds on the unpruned twigs had been determined. If, for example, it had been found that on the distal third of the average twig ninety-six per cent of the buds grew, on the central third eighty-four per cent, and on the basal third ninety per cent, that information could have been used in determining the percentage of the buds, on the parts left of the pruned twigs, that would have grown without the pruning. Statistical studies in which there is no way of evaluating influences other than the one being studied may give less dependable information than could be obtained by casual observation during intimate association with the material studied.

It may be that with vigorous young trees of varieties such as Grimes Golden, with which such very large percentages of the buds break anyway, cutting the twigs back severely does not cause buds to break that would otherwise remain dormant. It does not follow that with other varieties or with older trees or trees making weaker growth, such pruning would not cause buds to break that would otherwise remain dormant. And it is certainly true that rather severe cutting back of older trees will cause spurs to send out long shoots and will cause buds to grow that have remained dormant in the old wood for years.

Gardner found that with young trees, cutting back reduced the number of new shoots to form: the numbers being 6.9 to the twig, from the twigs with no pruning, and 5.8, 4.0, 5.1, 4.6, 4.6, 3.6, 4.6, and 3.6, respectively, to the twig, from the twigs having only the terminal bud removed to those having the most severe pruning. It is probable that more of the shoots from the unpruned or the lightly pruned twigs than from the more severely pruned twigs were short enough to approach the nature of spurs. Gardner emphasizes the fact that although the number of shoots to grow from a twig was smaller the more severely it was cut back, yet the shoots grew much thicker in the trees severely cut back; this because the new shoots grow from a much shorter stub. Thus let us say that from an unpruned twig thirty inches long, six shoots start and from the stub of a similar twig pruned back to ten inches in length, five shoots start. The shoots will certainly be more crowded on the stub ten inches long. In other words, by cutting back, the strong shoots, which tend to grow mainly near the end of a twig or a stub, are caused to come out nearer to branches that grew in the previous year. Of course with other kinds of fruit such as the peach, there would often be additonal crowding of the new growth in the top due to the formation of a greater number of branches on the new shoots.

Gardner found with these Grimes Golden trees, three years old at the beginning of the experiment, that the total number of inches of shoot growth from a twig was about the same regardless of the severity of the cutting back; the additional length of the shoots from the pruned twigs being only about enough to compensate for the smaller number. With trees several years older unquestionably the cutting-back would have increased the total amount of shoot growth; and when the trees were a year older cutting-back seemed to cause a small increase in total shoot growth with the Grimes Golden and Rome Beauty and a larger increase with Esopus.

Gardner suggests that with varieties like Esopus, which without pruning tend to make strong shoot growth only from the end bud, growth may be increased by cutting back the twigs. Probably total shoot growth could be increased by such pruning; but total growth would not be. With the Tompkins King apple trees the strong new shoots are made primarily from the end buds of the twigs, the heads being, therefore, very thin and the branches straggling. Yet in the experiments at Cornell University the dwarfing and reduction in fruiting of young trees of this variety caused by pruning was greater than with most other varieties. It should be emphasized that, while cutting-back tends to increase the total amount of shoot growth made by a tree, it does not increase but rather, as we have seen in Chapter 15, it actually decreases the total amount of growth made. The cut-back tree will be smaller than the unpruned tree by more than the amount of wood pruned away. While the unpruned tree makes less shoot growth, it makes more root growth and much new wood growth around twigs or older parts that would be cut away on the pruned tree, a thicker layer of new wood is also laid down around the trunk and older branches.

The great reduction in growth caused by the cutting-back is due to the removal of buds that would have formed spurs and the consequent reduction in the leaf surface. For example, in Gardner's results the average number of spurs formed on an unpruned twig was 18.5, on a twig cut back forty to fifty per cent, 6.6, and on a twig cut back seventy to eighty per cent, 2.7. Assuming that there were six leaves to the spur, each leaf averaging 2.5 square inches of surface, the spur leaf surface growing from the average unpruned twig would be 277.5 square inches, that from the average twig cut back forty to fifty per cent would be 99.0 square inches, and that from the average twig cut back seventy to eighty per cent would be 40.6 square inches. It is largely by the reduction in spur leaf surface that the total growth (including root growth) is reduced by cutting back.

Gardner found the total shoot growth on a tree considerably greater following cutting-back than following equally severe pruning as a thinning out of twigs. Though there was apparently no significant difference in growth of the tree trunks, the number of spurs was greater on the thinned than on the cut-back trees. In other words, cutting-back seems to cause the greater reduction in spur leaf surface and thinning-out the greater reduction in shoot leaf surface. Since there is so much more shoot leaf surface following cutting-back than following equally severe thinning-out, it is probable that in one year, at least, cutting-back may be less of a dwarfing process than is thinning-out. However, because of the dense growth resulting from repeated annual cutting-back, the loss of leaves and even of branches due to shade might cause the dwarfing effect while the tree is young to be as great with trees cut back as with those thinned out or greater. After the tree comes into bearing, however, thinning-out should have a greater dwarfing effect than would equally severe cutting-back. For, thinning out part of the branches does not generally reduce the fruiting of the parts left; cutting-back generally tends to reduce the fruiting, particularly toward the ends of the branches. Further, severe thinning-out tends to reduce the strength of the branches. Thus, with bearing trees thinned out severely, there is the dwarfing effect of pruning combined with that of heavy blooming and heavy fruiting and excessive bending of the branches, while with cutting-back the dwarfing effect of these last is reduced. It should not be understood that, with young trees thinning-out does not reduce the amount of fruit borne as compared with that borne by unpruned trees. It reduces the total crop of the tree by reducing the number of branches; but the individual branches left do not have their load of fruit reduced.

The fruit grower does not generally have to choose between the processes of cutting-back and thinning-out; but when one or the other seems necessary he should be able to weigh the dwarfing effect of either kind of pruning against the benefit that he expects from it and decide whether the benefit expected is worth what it will cost in reduced early fruiting. It is necessary to do some thinning-out of young trees. However, the young tree may well be left with the head much more dense than would be desirable with trees that have nearly reached maximum bearing capacity. It may be argued that thinning out the young tree should not dwarf it, because if the tree were not thinned out branches would be shaded out. However, before a branch is shaded out it has generally, through its leaf surface, made a large contribution toward the growth of the tree. One cannot be certain of cutting out only enough wood to prevent the shading-out of an equal amount. It is probable that, in the most careful pruning to let light into the tree, a considerable number of leaves are pruned off for each one that is saved from being shaded off. This view is supported by many of the experiments mentioned in Chapter 15.

With young trees that have not nearly reached maximum bearing, increase in size is generally more important than amount of highly colored fruit; and, since leaving the head thick increases the rate of growth of the tree, it is generally wise to do so even though a smaller percentage of the fruit is of good color. Further, while thinning-out increases the percentage of the fruit that is of good color, with young trees it does not increase, but generally reduces, the total amount of fruit of good color. For, in cutting away branches that would shade other branches much fruit that would be in good light would also be cut away. At the Cornell University Experiment Station (782) more fruit of good grade had been borne by unpruned trees by the time they were ten years old than the total amount of all grades borne by trees thinned out enough to expose nearly all of the fruits to the light. And so, by delaying the thinning-out of the trees one obtains more fruit of good quality, much more fruit of lower quality, and more rapid increase in bearing surface for the future. When the trees are older, they will generally need the invigorating effect of pruning and many small branches can probably be thinned out without reducing the amount of fruit borne.

Cutting-back also will occasionally be necessary even with young trees; particularly with young trees that tend to make very long shoots that branch only near the apex. With such trees the bearing surface sometimes remains too high and, more commonly, the tops are caused permanently to bend away from the prevailing wind. Alderman and Auchter (20) found that cutting back a branch did not increase its thickness at the base. However, it is very certain that continuous annual cutting-back does increase the thickness of a branch at its base relative to its length; that is, continuous annual cutting-back makes a branch or a tree more stocky. And Palmer (869) observed that young trees annually cut back stand much better against long continued rather strong winds than do trees pruned little. On the other hand, thinning out the secondary branches on a main branch tends to reduce the stockiness of the main branch. In California there has been introduced a system, known as long pruning, which consists of a considerable amount of thinning-out and little or no cutting-back; and in some orchards where the soil is very favorable for the growth of long shoots, which branch only near the end, a strong wind continuously from one direction may cause a very injurious bending. In fact, I have seen vigorous young pear trees with all of the branches growing flat upon the ground; in the same orchard trees with the branches cut back thirty to fifty per cent were standing erect and in good condition, though they were generally slightly dwarfed by the pruning. Certainly cutting-back was desirable in this orchard. However, it is reasonably certain that if the trees had not had so much thinning-out there would have been much less bending caused by the wind than there was on the trees that were thinned out but not cut back. The growth at the end of the branches would for a few years have been slightly shorter, while the main branches would have been stronger due to the thickening caused by the larger number of secondary branches along them. At least observation upon many branches suggests that this is true; and Blake and Conners (770) seemed to find that the increase in trunk circumference is determined not alone by the amount of twig growth, but partly by the location of the growth on the trunk. Where branches were left low on the trunk the circumference at the base increased more rapidly than where the tree made an equal amount of twig growth further from the base of the trunk. If having much of its branch system near the base increases the size of the trunk at the base, it should be expected that secondary branches near the base of a main branch should increase its basal circumference more than if the same secondary branches were farther out from the base.

While some bending of the tree away from the wind may not be as undesirable as the dwarfing effect of cutting-back, there will often be bending so injurious that cutting-back will be wise. However, only enough cutting-back should be done to correct the injury; consideration being given to the fact that cutting-back prolongs the time before the tree is large enough to bear profitable crops. We have seen that as the tree grows older annual cutting-back may be increasingly desirable, and the correcting of smaller defects can be delayed until that time.

Removal of excess branches, particularly lower ones. Whether or not a branch that must eventually be removed may be left temporarily depends upon the nature and position of the branch and upon the growth habit that characterizes trees of the variety concerned. A branch that will injure another that is to be permanent should not be left. Upright vigorously growing branches, such as water sprouts, should not be left unless they are to be used as permanent branches.

We have seen in Chapter 4 that root growth is generally more rapid in late summer after shoot growth has ceased, probably because after shoot growth ceases there is a larger supply of organic nutrients that may move to the roots. It seems probable that the earlier in summer shoot growth ceases on a branch the sooner organic materials elaborated in its leaves will begin to move in large quantities to other parts of the tree, such as the roots; and the larger will be the percentage of such products of its leaves that will be used by other parts of the tree than that branch. With some varieties there is a tendency for shoot growth to continue later in summer on the upper branches than on the lower ones. With Beurré Bosc pear this tendency is very striking; and the amount of leaf surface on the lower branches is, relative to their dry weight, much greater than on the upper more vigorously growing branches. For example, in the Cornell University orchard (782) it was found that in early autumn there were on the upper late-growing shoots eight square inches of leaf surface to a gram of dry matter in the shoot as against 16.1 square inches of leaf surface to a gram of dry matter in lower, smaller shoots that had ceased growth much earlier in the summer. In that orchard the leaves on lower branches as well as those on upper ones were in a healthy condition until after freezing weather; and I know of no reason to think that they were less efficient in photosynthesis than were the leaves on the upper branches. If their leaves were as efficient, these lower branches must have contributed toward the growth of the remainder of the tree a much larger percentage of the products of photosynthesis by their leaves than did the upper branches. And such lower branches during the time they are left on the tree must be relatively more beneficial to the remainder of the tree than they would be if they grew as vigorously and continued to grow as late as those in the upper parts of the tree. Further, since such branches grow more slowly than the remainder of the tree, the longer they are left on the tree the less severe pruning their final removal will represent.

This applies, of course, to secondary branches toward the base of main branches as well as to the weaker branches on the trunk.

Such branches are often removed long before they come to be injurious; the grower thinking that since they must come out eventually their removal as soon as possible will cause more growth to be made in parts that will not have to be removed. However, we have seen that the increased growth in parts left is seldom, if ever, equal to the new growth that would have been made on the parts removed. And the trees having a smaller leaf surface will make a smaller root growth, and during succeeding years a smaller growth in the parts left. Except during the first year after the pruning a tree does not gain in height more rapidly by having lower branches cut away. In fact, if many lower branches are removed, the reverse is likely to be true. Howe (834) found no increase in height caused by removal of the lower branches of apple trees to train them to high heads. At Cornell University the trees having very little pruning gained in height as fast as any others, and with some varieties faster; though with all but one of the systems used there was no cutting-back of the uppermost branch. With very severe pruning away of the lower branches growth in the branches left may, except in the first year after the pruning, be greatly reduced. Thus Hawley (827) found a marked reduction in the growth of white pine trees when the lower branches were kept removed to within a few whorls of the top shoot. At Cornell University (782) the fruiting of young trees seemed to be strikingly reduced by the removal of these lower branches and by removing from the top all branches that would later become undesirable. Leaving such branches until they are near to becoming injurious will increase the amount of fruit borne while the tree is young and accelerate the rate at which the tree increases in size.

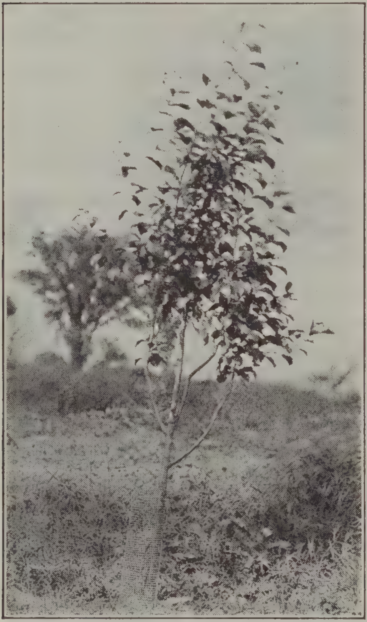

FIGURE 21. Such cutting away of the secondary branches from the bases of the main branches, reduces the leaf surface and growth. It seems best, with some varieties, to leave such lower branches to fruit during a few years before they are removed.

The problem is somewhat different, however, in the case of undesirable branches that grow more rapidly than the main branches. With some varieties, such as the Rhode Island Greening apple and many varieties of peaches, the lower branches may grow faster than the others. Such branches use for their own growth more nearly all of the material elaborated in their leaves, contributing a smaller percentage of it, if any, toward the growth of branches that are to remain; and the longer they are left the more severe will be the pruning that their final removal will represent. Generally with such varieties lower undesirable branches should be removed as soon as they appear. However, sometimes they may be weakened by bending them or by cutting them back in summer, and their leaf surface may thus be caused to contribute to the growth of the roots and, through increased root growth, to the growth of the remainder of the tree.

In leaving lower temporary branches as well as in spacing permanent ones, it should be considered that a lower branch may strikingly inhibit the growth of one above it or of the trunk. We have seen in Chapter 1 that the nutrients seem to move upward rather directly from the roots to connecting branches; and that they apparently move most rapidly in the bark. A branch directly under another would be expected therefore to reduce the area through which material moved to the upper branch. Probably if the lower branch is considerably the smaller no measurable harm will be done; but several small ones below another branch seem appreciably to reduce its growth. In the Cornell University orchard, unless the amount of pruning of the lower branches was rather severe, trees with a central leader and a considerable number of branches coming from near the same level on the trunk have had the leader gradually choked into a much weakened condition by the growth of the lower branches. And with trees trained to a modified open head, where more than two branches started from the uppermost or leader branch at the same level, the growth of these branches has seriously checked the leader branch, unless they were pruned much more severely than the leader. As a rule, no more than two branches should start from near the same level; and these should be on nearly opposite sides of the tree. Further, the permanent branches should be so disposed that after the lower excess branches are removed there will be uninterrupted connection between each branch and the roots. Lateral branches left thick around the main branches seem to check the growth of the leader part of the main branch. In other words, both on the trunk and on the main branches there should be careful spacing in order to avoid interfering with the nutrient supply of the part above.

Dwarfing individual branches by pruning. It is often necessary in training trees to reduce the size of one branch as compared with another which may be a leader. This is more often than otherwise done by pruning. There has recently been a tendency to stress the view that the invigorating effect of pruning is exerted only near the point where the cut is made; the view being generally that the invigorating effect of pruning is due to a chemical change, such as the development of a more narrow carbohydrate-nitrogen ratio, that favors growth. If a single branch is pruned, any possible invigorating effect on the remainder of the tree will be divided among so many growing points that it may not be measurable. The growth near the point where the cut is made certainly appears more vigorous. However, a part of this is due to the fact that the buds near the cut end are given the advantageous positions of end buds. We have seen, also, that cutting back trees that bloom to the ends of the branches may strikingly invigorate the part left, due to the removal of fruit buds and the reduction of the depleting effect of excessive blooming and the setting of excessive numbers of fruits. Such an influence is probably almost entirely localized in the branch pruned. However, not all the effect of pruning is localized.

If the increase in vigor due to pruning were all due to a reduction in the number of growing points requiring nitrogen and therefore to an increase nitrogen supply to the parts left, the invigorating effect should all, or nearly all, be on the pruned branch. For Auchter (30) and others have shown that nutrients tend to move, in the main, from given roots to the branches with which they connect. However, if the increased vigor were due to an increased water supply in proportion to the evaporating leaf surface left, then, while the pruned branch might benefit the most largely, one branch could hardly be oversupplied with water while another had a serious water deficit. For the water system of a tree seems to be connected to such an extent that it will move to the greatest osmotic pull; and this pull increases as the deficit increases.

While it is not easy to measure the invigorating effect in one branch caused by pruning another, it is easier to measure the reduction in the invigorating effect in a pruned branch caused apparently by the dissipation of a part of the invigorating influence among other branches that are unpruned. If the invigorating effect of pruning were all near the point where the cut was made, the dwarfing effect on a pruned branch should be no greater if the remainder of the tree were not pruned than if the entire tree were pruned. However, the dwarfing effect of pruning a given branch seems to be much less if the remainder of the tree is also pruned.

The effect of pruning as a dwarfing process, in so far as individual branches are concerned, seems long to have been recognized by most people who have pruned trees to shape them. Thus, if one wishes to suppress a branch as compared with another or with the central leader of the tree, one cuts it back or cuts away some of its secondary branches. Even though the cutting-back may not be severe, the effect in a few years becomes evident. The unpruned part of the tree will have gained markedly in size as compared with the pruned branches. Pickering (872) gives results showing the marked dwarfing effect of pruning individual branches. From each of a number of trees he selected a number of twigs thirty-six inches long, the diameters of all twigs being about equal. Some of these were cut back to six inches in length, some to twelve, some to twenty-four, and some merely had the terminal buds removed. At the end of the growing season following the pruning these twigs and the new shoots from them were weighed. Considering the weight of the twig cut back to six inches — with its new shoots — as 100, the relative weight of that cut back to twelve inches would be 179, of that cut back to twenty-four inches, 310, and of that left thirty-six inches long, 562. The pruning, however, had stimulated increased growth on the part back of the pruned twig. When this was taken into consideration, where the branch pruned to 6 inches was considered 100, that pruned to twelve inches was 123, that to twenty-four inches 148, while that left thirty-six inches long was 218. When the weight of the original twig or stub was deducted and only new shoots were considered, the weight was still appreciably greater in case of the unpruned or slightly pruned branches, in spite of the fact that with the unpruned branch much new growth would be laid down around the additional thirty inches of original twig length. Cullinan (801), also, found much less shoot growth made from pruned than from unpruned branches on the same tree.

It is evident from the results of Gardner (813) and many other workers that when the whole tree is cut back there is not such a large reduction in growth. This suggests that when only one branch is cut back the new growth on that branch is not as great as it would be if the entire tree were cut back as severely; and there is more direct experimental evidence pointing to the same conclusion. In the Cornell University orchard (782) in the spring of 1919, thirty pairs of 1918 twigs were selected, each twig being on a different apple tree in a nursery three years from the planting of bench grafts. The twigs averaged 29.2 inches in length and were cut back to an average length of 9.9 inches. Each pair was composed of one twig on a tree all of whose twigs were cut back about as severely as was this selected twig, and one twig of the same length and thickness, in a similar position on another tree and cut back to the same extent, but with the other twigs of the tree left unpruned. In the summer following the pruning the average amount of shoot growth from a cut-back twig on a cut-back tree was 32 inches, while the average amount on a cut-back twig on a tree the remainder of whose twigs were not cut back was 9.9. It seems very certain that with the pruned twigs on otherwise unpruned trees whatever increase in vigor there was was distributed throughout the top. In other words, the response to pruning was not localized.

Auchter (746), working in Maryland, cut back to stubs about two feet long all of the limbs of some peach trees. On other trees he cut back only one limb each to such a stub. The new shoot growth made in the following season on the average stub on trees all of whose limbs were pruned amounted to 50 feet, while that from the average stub on trees the other branches of which were not pruned was but 4.3 feet. In some way the unpruned branches of a tree have reduced the vigor of growth in the pruned branch. It seems probable that the invigorating effect of the pruning was distributed throughout the top of the tree. In fact, Auchter has given some further evidence in favor of such a view. In this same orchard the average length of terminal twigs on unpruned trees was but 1.7 inches, while on unpruned limbs of trees, one limb of which was severely pruned and one moderately pruned, the average terminal twig length was three inches. And on lightly pruned trees the average twig length was 2.5 inches; while on lightly pruned limbs of trees, one of whose branches was pruned severely and one moderately, the average twig length was nine inches. While with these somewhat devitalized peach trees the evidence may not be very conclusive, cutting back individual branches seems to have increased the growth on unpruned branches of the same tree.

These results are in agreement with practical experience in shaping trees, pruning a single branch dwarfing that branch more than pruning a whole tree dwarfs the tree. And generally a rather small amount of pruning will reduce the size of a limb relative to that of the tree as a whole. While cutting-back is more commonly practiced in suppressing a branch, thinning out the secondary branches of a main branch seems to have the same effect. Certainly such thinning-out reduces the thickness of the branch at the base as strikingly as does cutting-back, or more strikingly.

If it is desired to suppress the growth of a branch that must be removed eventually but is left temporarily for its effect on root growth and for the fruit it may bear, it may be best to cut back in midsummer, when there is little or no invigorating effect following the pruning. Such a branch might thus be permanently weakened in growth relative to the other branches, and its removal might thus be delayed longer without harmful effect.

There might be conditions under which cutting back a branch would dwarf it much less than would equally severe thinning-out. In the case of a variety, such as Wealthy or Wagener apple, that tends to bear many fruits terminally and laterally on twigs of the previous season, there seems to be, in addition to the direct dwarfing effect of blooming and fruiting, an indirect effect due to the bending of the ends of the branches. Cutting back the ends of the branches would reduce the amount of such sharp bending or prevent it altogether; and by removing the terminal and most of the lateral fruit buds it would reduce the depleting effect of the excessive bloom and the excessive number of fruits. Thinning out branches would, of course, not reduce the amount of bending near the ends of the branches and would leave thick masses of lateral fruit buds to check growth. With such bearing trees cutting back the twigs may dwarf the branches very little.

Influencing the relative size of different branches by removal of blossoms or fruits. Since fruiting strikingly dwarfs a tree or branch, it seems probable that the shape of the tree, particularly the relative size of the different branches, might be influenced by the removal of blossoms or fruit from one or more of them. Such a practice seems long to have been used in training trees against walls or trellises. Thus, Du Breuil (808) recommends that as large a quantity of fruit as possible be left on the branches that it is desired to suppress, and that most of the young fruits be removed from branches that it is desired to encourage. It would seem that more use might be made of this principle in training young standard trees. Thus, if it is desired to have the uppermost branch of a tree the largest, it might be possible to increase its growth by removing most of the blossoms or young fruit from it; and the dwarfing effect of pruning the other branches might be avoided, in part at least. There is a nice question as to whether it would be better to remove the bloom, or to remove the fruit after the "June drop." With apples and pears at least less work is required to remove the bloom while it is young than to remove the young fruit before the "June drop." After the "June drop" the fruit adheres more strongly but there is much less to remove. When only one year is considered, it seems that removing the bloom should be more effective than removing the fruit after the "June drop." For we have seen that, if the bloom is removed before it is fully open, the leaves near that point sometimes seem to grow larger; and it is probable that the shoot growth of that year will be increased. However, both the amount of new growth and the size of the leaves are reduced by a heavy bloom, even though the bloom is removed. And we have seen in Chapter 12 that removing blossoms tends to cause fruit buds to form for the next year even with varieties that tend to bloom only in alternate years. Removing the fruit after the "June drop" does not seem to have that effect. With such alternate bearing varieties it is possible that, considering more than one year, the dwarfing effect of annual blooming might be greater than the dwarfing effect of biennial blooming and setting of fruit, provided the fruit is removed soon after the "June drop." In experiments with apples at Cornell University removing of blossoms or of fruit has not appreciably influenced the size of apple trees or of apple branches.

Polarity and the influence of bending branches in the shaping of trees. It is well known to fruit growers that generally with upright twigs the end bud grows into the longest shoot; and that with many varieties only a few buds near the end tend to grow into shoots of considerable length. The other buds may open into very short shoots or into spurs, or they may remain dormant. If the end bud is cut off, the next bud back of the cut generally grows the most vigorously. If the twig is cut back severely, the bud nearest the cut end — a bud that but for the pruning would remain dormant, or would open into only a spur or short shoot — will make the long terminal shoot; and a few other buds will grow into shoots. (We have seen that in Gardner's experience fewer shoots but longer ones were formed after such cutting.) With stem cuttings the tendency is for roots to form only at the basal end.

This polarity has been a subject of much attention by botanists. Sachs (891) suggested that there may be substances present in the tissue in small quantities that promote the formation of shoots or leaves or other structures and that move in definite directions, those concerned with shoot growth moving toward the apex and those concerned with root formation moving toward the base. Goebel (817) is inclined to accept this view, at least in a modified form. He says that the vegetative point serves as a center of attraction for constructive material necessary for the formation of new organs. Loeb (855) at first suggested that there may be a substance moving backward from a growing apical bud (and from growing buds near the apex) that inhibits growth from lower buds. However, he later (858) seemed to reach the view that the inhibition of growth may result merely from the fact that the material available for growth moves toward the apical bud. Thus, when a leaf of *Bryophyllum calycinum* was left attached to a piece of stem, the leaf did not form roots or shoots, though such a leaf detached from the stem would form both. When the leaf was attached to the piece of stem, the roots and shoots grew on the stem; and a number of measurements showed that the growth from a small piece of stem attached to the leaf was just equal to the growth made from a similar leaf not attached to a piece of stem.

McCallum (861), working with the scarlet runner bean, seemed to find that the total amount of available organic nutrients cannot be the determining feature as to whether or not a basal bud will grow. For with the most vigorous plants the buds within the cotyledons would not grow; but when the epicotyl was removed two shoots would grow from these buds. Even when he removed the cotyledons, leaving the two buds, and, after growing the plant in the dark so that the reserve organic nutrient supply would be low, cut away the plant above these buds, they still grew. He found also that the growth of these buds could not be induced by placing the plant in a moist chamber under conditions such that transpiration was reduced to nil; though when the tops were removed from plants growing in soil so low in moisture that the plants were wilted, although no water was applied to the soil, these buds started development. In some way the growth of these buds was inhibited by the growing top and this inhibition seems not to have been caused by a reduced water or organic nutrient supply to the buds. However, we cannot say that it was not caused by a carbohydrate nitrogen ratio unfavorable for growth. Shading is one means of narrowing the carbohydrate nitrogen ratio.

On cuttings of the bean, McCallum found, roots would form only at the base unless a notch was made in the stem, when roots would form above the notch. When a section of the stem was etherized but not killed, roots grew just above the etherized section. Harvey (825) killed a section of the stem of a bean plant with steam. Although enough water passed through this killed area to keep the plant growing vigorously, roots formed at the base of the live part above the killed area, and shoots grew from dormant buds near the top of the live part below the killed area. Harvey assumed that since the water moved through the killed section of the stem, mineral nutrients and other soluble substances must have moved through and that the polarity of the two parts (that below and that above the killed section) could not have been due to a change in the supply of any soluble substance. However, if the view supported by Curtis is true, and both organic substances and nitrogen move — whether upward or downward — primarily in the phloem, then growth-promoting or growth-inhibiting substances, as well as nitrogen and organic nutrients, could not have passed the killed section.

Reed and Halma (885) have supported the view that a growth-inhibiting substance moves backward from the growing apex. Working with twig cuttings of the Chinese lemon, they found polarity very definite. With vertical twigs, only buds near the apex or buds below a ring or a notch would grow. With cuttings suspended in a horizontal positon, the buds on the upper side throughout the length of the twig would grow, the buds on the lower side remaining dormant. If such a horizontal cutting with growing shoots along the upper side were turned over so the shoots would point downward and the dormant buds upward, these dormant buds would grow; and the growth of the downward-pointing shoots would be inhibited. It does not seem to me that any of these results furnish more convincing support for a view that there is a growth-inhibiting substance moving away from the growing apex or to the lower side of a horizontal twig than for a view that there is a growth-promoting substance moving toward the growing apex or around to the top of a horizontal twig. If either kind of substance exists, it must move in the bark, probably in the phloem, and therefore not be able to pass a ring or a notch in the bark, and it must be able to move through the bark around the cutting from the upper to the lower or from the lower to the upper side of the cutting. If, as suggested by the work of Heinicke (171), catalase activity of the tissue is a fair measure of the carbohydrate nitrogen ratio, all of the treatments that cause a bud to grow also increase the supply of nitrogen relative to carbohydrates. For catalase activity is higher at the end than at the base of a cutting and higher just below than just above a ring or a notch in the bark.

McCallum suggests that since the protoplasm of the entire plant is connected a stimulus could possibly be transmitted in that way and influence the growth of buds. Morgan (865) says that polarity must be due at least in part to some physical factor and suggests different tensions, perhaps electrical, in the tissue; and Harvey (825) thinks that biological polarity may be electrical polarity; and a given process, such as shoot growth, at one region or pole is necessarily accompanied by a reverse process, such as root growth, at the other region or pole. Child has made extensive studies concerning polarity in both plant and animal tissue. He finds that there is a definite gradient as to susceptibility of the protoplasm to toxic concentrations of various substances or to lack of oxygen. The gradient is found also with reference to the penetration of dyes and the rate of reduction of a salt, such as potassium permanganate. In growing tissue the most susceptible protoplasm is that at the vegetative point; the gradient being away from this point. He does not think this gradient can be due to the transport of nutrients, since it exists in such simple tissues — even in single cells — having no specialized tissue for transporting substances. In fact, he thinks it is due to external influences; for it can be reversed by means of treatment with weak concentrations of depressing agents, the most active protoplasm at the dominant point being depressed the most rapidly, and thus due to this greater depression becoming the less active. Child and Bellamy (792) have found that in *Bryophyllum*, the plant which has been used so extensively in studying polarity, the gradient can be modified by means of treatments that they do not think can interfere appreciably in the transport of nutrients. We have seen that with this plant, when the leaf is attached to the stem or to a piece of stem containing a bud, the shoot growth (the dominant point in the gradient) is on the stem; but when the leaf is detached, there will be shoot growth from the leaf. These workers found, however, that when the petiole was surrounded by water at a temperature of 2.5 to 4° C. for a few days, shoots would grow from the leaves. In other words, the leaf behaved, as to polarity, as if it had been severed from the stem. With the scarlet runner bean they found that exposing the section of the stem, above the cotyledons but below the first pair of leaves, to a temperature of 3° to 4°, and usually even to 5° C., would cause the buds in the axils of the cotyledons to grow. If a section of the stem above other dormant buds was cooled in the same way, such buds just below the cooled section would grow. When the cool water was removed from around the stem, growth from the buds below was again inhibited, unless the shoots had grown to several centimetres in length. Reed (879) seemed to find that the buds of *Bryophyllum* leaves will generally grow if that part of the leaf containing the bud is in contact with water or very moist air. His results may render necessary a reëxamination of the work of Child and Bellamy with this plant as well as that of Loeb, though I do not see how they could be of much importance in interpreting the results of McCallum with the bean or of Reed and Halma with Chinese lemon twigs. It seems to me that they suggest only that *Bryophyllum* is a questionable plant with which to study polarity.

Child and Bellamy are inclined to think that this gradient — the dominance of one point over another — may be explained by the work of Lillie (850–854) who has studied the transmission of stimuli through protoplasm. According to this worker such transmission is by means of an electric current generated at the point of excitation, due to the fact (as he seemed to find) that the unexcited surface layer of the cell protoplasm is more permeable to positive than to negative ions, and is therefore electrically polarized, and that excitation increases permeability to negative ions and brings about depolarization. The electric current thus generated at the point of excitation (with the plant the growing point) promotes depolarization progressively away from the point, at the same time reëstablishing polarization at this original point of excitation. While such a theory might explain the inhibiting influence of a growing point over other possible growing points, it does not, it seems to me, explain how that particular growing point first acquired ascendency.

The results of Child and Bellamy, in changing the polarization of *Bryophyllum* leaves or of parts of bean stems by cooling a section of the petiole or of the stem, are in agreement with the results of McCallum, who changed the polarization of parts of the bean stem by means of mild etherization of a section. These workers do not think that the transport of nutrients could have been appreciably influenced. However, if it should be found that transport of both organic and inorganic nutrients is mainly through the phloem and is hastened by the streaming movement of the protoplasm in the sieve tubes, these treatments would probably be found to influence the transport of nutrients. For, the streaming movement is known to be checked both by anæsthetics and by low temperature (Ewart 809a). In the plant physiology laboratory of Cornell University the streaming movement of *Nitella* is observed to be stopped or nearly so by temperatures such as Child and Bellamy used. If polarity is due to an electrical influence transmitted through the protoplasm from the growing points to other parts — continuity of the protoplasm from cell to cell being assumed to make such transmission possible — then, in the higher plants, the transmission must be through the phloem; for cutting through the phloem will divide the plant into two polar systems. That is, shoots will tend to form at the apex of the part below the cut and roots at the base of the part above the cut. In fact, whatever the polarizing influence may be, it must be transmitted through the phloem. As to why a given point should become the strongest growing point and, therefore, acquire a position such that it can inhibit the growth at other points, and as to why that inhibition should be stronger at some buds than at others, it would seem that anatomical studies concerning the connection of the different buds with conducting tissue might yield some information. This might be true whether what determines polarity is the movement of nutrients or some particular nutrient in largest quantities to dominant buds or shoots; or the movement of some inhibiting substance from growing shoots; or an electric current originating at dominant positions.

It seems desirable thus to have surveyed the experimental literature, in order to avoid the danger of drawing erroneous conclusions from superficial considerations; although it seems to me that we are far from knowing the explanation of polarity and that none of the above-mentioned studies can as yet be applied in practice. But a knowledge of polarity, regardless of its explanation, is of considerable practical importance.

We can say with certainty that growth of the apical bud or of buds on the upper side of a horizontal branch tends to inhibit growth of other buds; though we do not know how inhibition may be accomplished.

The amount of the inhibition is much greater with some varieties than with others, and is occasionally modified through other influences than cutting, bending, ringing, and notching. Thus in a cultivated soil many more new shoots will grow from a central shoot of a young tree than will grow from such a shoot of a young tree in sod; and generally when a sod orchard is brought into cultivation many buds low in the tree may be caused to grow. When a vigorous twig undergoes any kind of check, stronger shoots may grow from basal than from apical buds. Thus when a tree is transplanted, if long twigs are left unpruned, the growth from the apical bud and from most of the lateral buds during the first two seasons following transplanting may be very weak; and strong shoots may grow from the base, as shown in Figure 22. When the tree was planted all of the twigs were cut back except that which formed branch *a*. From all of the other twigs a fair growth was made in the first year and good growth in the second year. None of the buds of *a* made more than very slight growth in the first year, and the growth from the apical bud and from lateral buds toward the apex was weak in the second year. But buds near the base made strong growth in the second year. This tendency for weakened polarity to be associated with a weakened condition of the branch may be in agreement with the experience of Appleman (23) who found polarity less marked with potato tubers after they had become old and shriveled.

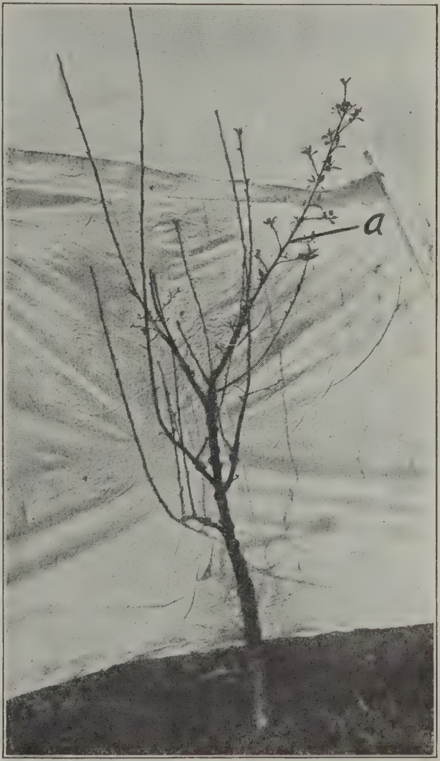

FIGURE 22. The branch at *a*, unpruned when planted, has made very little growth during two summers, and shoots from its base have grown more than any from near the terminal.

On the other hand, with vigorous trees grown in a cultivated soil, in which the nitrogen supply is abundant, branches start farther from the apex of a twig or shoot than with trees grown in sod or under other conditions unfavorable for growth. In fact, severe pruning often causes such branching far back of the apex. We cannot be certain that such invigorating influences weaken the polarizing influence. They may so increase the tendency of all buds to grow that the inhibiting influence from the growing terminal, though not reduced, does not prevent growth. When a twig is cut back, the leaves from the lateral bud at the end of the stub do not open as soon as do the first from the terminal bud of an unpruned twig. It may be that on pruned branches the development of a strong inhibiting influence from the terminal shoot is thus delayed until buds — that without the pruning would be inhibited — have started to grow.

Polarity is influential in determining the nature of response to pruning. For example, when a branch is cut off or cut back to a secondary branch, new shoots generally do not grow from around the wound left, unless dormant buds happen to be near the lower side. However, if a stub is left, such new shoots tend to grow from near the end of the stub. If a stub is not left, growth in the branch above the wound seems to inhibit growth from dormant buds around the wound; except on the lower side. The buds just below the wound may be influenced as they would be if a ring or a notch were made above them. However, all of the dormant buds are more apt to be cut away with the branch on the lower than on the upper side of the wound.

The degree of polarity which characterizes the branches of different kinds or varieties seems to influence the amount of dwarfing that will follow annual cutting-back of young trees. Thus, polarity is so strong with branches of young fig trees that cutting the twigs back lightly does not seem appreciably to reduce their leaf surface. It merely causes about the same amount of new shoot growth to start from a little farther back on the branch, buds back of the terminal nearly all remaining dormant. Under some conditions Northern Spy apple, Bartlett pear, apricots, and some plums behave similarly. On the other hand, with McIntosh, Rhode Island Greening, and Baldwin apples and most varieties of peaches, under many conditions at least, polarity is not so strong but that many lateral buds grow into branches; and so, while cutting-back reduces the height of the tree, there cannot be a compensating thickness of the head without causing an injurious amount of shading.

It may be of slight interest to know whether or not the increase in vigor of the growth after pruning will be greater if, in cutting back a twig, one cuts to a strong, large bud. According to Koopmann (846), when the growing point of a shoot is pinched off in summer and the twig is pruned back to the first bud in spring, the resulting growth is longer than from an unpinched twig which is cut back to the same height in spring. Crandall (82), however, did not find any difference between the large buds from strong shoots and smaller ones from weaker shoots when used in propagation. Certainly a very weak bud will make a strong shoot when in an apical position; and if the amount of resulting growth should be greater when one cuts back to a large bud, the difference would probably be too small to be significant in American orcharding; though it might be of some importance in the detailed pruning that is practiced in some European countries. It may be that, when a branch is trained horizontally so that all of the buds on the upper side of the twig have equally favorable positions as to polarity, the strongest shoots will grow from the largest buds on that upper side. In that case, if it should be desired to have the longest shoot at the end of the twig, it might be best to cut to a strong bud.

Some think that the shoot from the terminal bud will be stronger than that from a lateral bud to which a twig may be cut, the terminal bud being larger and opening more quickly in spring. I know of no significant data concerning the problem. Even if the terminal bud should form a stronger shoot than would a lateral bud placed by pruning in an apical position, it does not follow that more growth would be made from the twig. It may be that by opening earlier the shoot from the terminal bud would have a greater inhibiting influence on the lateral shoots near it, a large percentage of the total growth from the twig thus being in the apical shoot, generally an undesirable condition.

Of much importance in training trees is the shifting of polarity when branches are bent. The position of most active shoot growth may be changed, or the vigor of growth may come to be more nearly equal throughout the tree. With some kinds, if a growing shoot is bent to a horizontal position, the end may bend upward and continue growth as shown in Figure 23; but generally shoots will start also just back of the bends. If a dormant branch is bent downward to such an extent that the terminal twigs are lower than some other point, the longest shoots may grow from buds at the highest position, the terminal growth becoming rather weak. Sharp bending may cause a very strong shoot resembling a "water spout" to grow near the highest position on the branch. With grape canes permitted to droop from the top wire of a trellis, the strongest shoots will be near the base of the cane, the highest point; while with canes trained upright the strongest shoots will be near the end of the cane. A. M. Burroughs in some unpublished work seemed to find that grape shoots will make more growth if trained upright than if permitted to assume a drooping position; and Edminster (119) found that upright shoots of young apple trees tend to be the longest.

As to the effect of bending branches downward on the total amount of growth that will be made from them in succeeding years, we have little conclusive data. Gardner (813) seemed to find that bending downward strong dormant twigs of young apple trees did not greatly change the amount of growth made from them in the succeeding growing season. On the bent twigs there was a tendency for the strong shoots to be toward the base and for the spurs to be toward the terminal. With one variety, Grimes Golden, the total shoot growth was about the same from bent and unbent twigs; but with Esopus bending seemed to increase the amount of shoot growth. This difference may have been due to a difference in response by the two varieties; but it may have been due to a difference in the nature of the bend. It seems that if the twigs were in an evenly horizontal position,

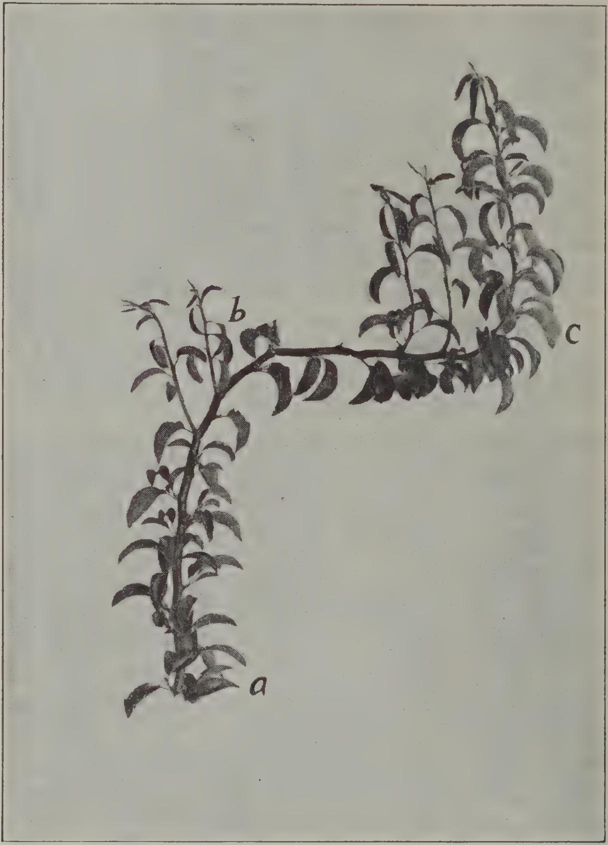

Figure 23. A shoot bent to a horizontal position from the nearly upright position *a b*. The bending was done July 10th at Davis, California, when the shoot was still growing; and so the growing terminal curved upward. If a dormant branch were so bent in the spring, the new growth would probably all have been in buds back of the curve as at *b*. (After F. E. Gardner.)

such that none of the shoots would be strongly dominant, more shoots might grow from it than if there were a sharp upward curvature toward the middle and a strong dominance in the shoot near the uppermost point in the curve. Halma (823) seemed to find an increase in the amount of shoot growth from strong straight branches of Eureka lemon caused by bending the branch to an evenly horizontal position; the average length of the new shoots on the bent branches was less but there were more than twice as many of them.

The later influence from such bending would not all be due to the influence of polarity, even if the initial influence should be. In several ways bending must eventually exert indirect influences on the growth of the tree. If it should increase the fruitfulness, that would tend to reduce growth. On the other hand, if it should increase the spread of the branches and thus the number of leaves that can be exposed to the light, it might increase growth; though this increased spread would generally be obtained through a reduction in height. When the bending is so sharp that the dominant shoot is well back from the end of the branch, the tendency is unquestionably to reduce the height without appreciably increasing the spread; and the head may become so dense as to compel the cutting out of more branches than would be necessary if the dominant shoots had grown from near the ends of the branches. In the case of varieties like Northern Spy apple and many varieties of pears with which growth of all limbs tends to be very nearly upright, the heads thus being dense and much foliage being thus shaded out, it would seem that bending the branches outward, far enough to let in light, but not far enough to cause the dominant shoot to be back of the end of the branch, might increase the effective leaf surface and, therefore, the growth or fruitfulness of the tree. With Northern Spy not only is there a shading-out of the foliage in the young tree; but polarity is so strong that an exceptionally large percentage of the buds remain dormant or make only very weak spurs. Bending the branches of young trees outward, but not completely to a horizontal position, tends to cause some of these buds to grow and some of the weak spurs to become stronger or to become twigs. This it seems can be accomplished without preventing the growth from being the strongest at the ends of the branches. As to whether or not this increases the total leaf surface or only increases leaf surface toward the base at the expense of leaf surface at the ends of the branches, we have no conclusive evidence; but it seems that with such varieties — the trees of which form such compact upright heads that even some pruning to open out the head does not reduce the leaf surface (782) — bending outward but not too far downward should increase the well-exposed leaf surface; and by that means it should increase growth.

We have seen that the response to bending is a change in polarity; and there is no reason to think that there is such a starving of the roots by shutting off the organic nutrient supply as that following ringing. There is, therefore, no reason to think that there can be such a dwarfing effect as that following ringing.

Bending is used as a means of throwing branches of young trees into fruiting. As to how this is accomplished we cannot say. Halma found many more shoots but shorter ones — shoots of the fruiting type — on bent Chinese lemon branches. If the leaf surface should be increased as a result of such increased shoot growth, that should increase the concentration of carbohydrates and therefore the fruitfulness. Further, the first spurs formed on a young upright tree are often weak; and if bending should increase the size of these — either by reducing the injury from shade or by reducing their disadvantage caused by polarity — it might result in earlier fruiting. A. M. Caldwell has practiced a system of bending down branches, by which young Bartlett pear trees in California — growing under soil and climatic conditions such that very upright growth is made — can be caused to bear heavy crops considerably younger than would trees left to grow normally (Tufts, 907). Such systems of bending should have comprehensive study. While it seems possible that the bending may be done in such a way that the only dwarfing effect on the tree is that caused by the fruit borne; it is certain that, as practiced in some orchards, bending must cause also a large dwarfing effect due to the fact that the largest shoots from each branch are not at the end but back toward the center of the tree, the height of the tree being greatly reduced without a compensating increase in spread; and the new shoots, being forced within a small radius from the trunk, are so crowded that much cutting away of overcrowded branches becomes necessary. Of course, as much growth could be made from the ends of the branches without causing such excessive thickness of head. However, as practiced in parts of California, such bending obviates the necessity of rather severe cutting back of strong growing Bartlett pear trees and, thus, in spite of the dwarfing effect earlier fruiting seems to be a means of getting the tree to full bearing size at an earlier age.

Further, there may be conditions under which it would be wise so to hasten the fruiting of young trees, even though they might thus be so dwarfed in growth that the reduction in fruiting later would be enough to reduce the total amount borne by the time the tree is, let us say, fifteen years old. The grower's financial condition may be such that he must have an income from the trees as soon as possible. Or there may be danger that many of the trees will be killed while rather young; perhaps by a severe freeze or, in the case of pears, by blight. Under such conditions it would be wise to bring the trees into profitable bearing as quickly as possible, even at the expense of a considerable reduction in growth and later possible fruiting.

If it should be true that individual branches will always make more growth if left in an upright position, it might still be true that bending some of the branches of an upright growing tree would not reduce the total growth of the tree. If one branch were bent downward and the others left in an upright position, that one branch might have its growth reduced as a result of the increased polar dominance of the other branches whose growth would be thus increased. If this should be true, then bending might be a desirable means of forming a good framework in the tree. If bending downward all of the branches, except the uppermost one, should increase the growth of that uppermost one and slightly reduce the growth of the others, such a practice might be more desirable than cutting back all of the branches except the uppermost one. For it might not reduce the size of the tree as a whole, while cutting back branches would.

Further such bending would certainly widen the angle by which the branch approaches the trunk, and thus tend to strengthen the union of the branch with the trunk.

Obtaining strong unions of the branches with the trunk. MacDaniels (862) has studied the unions of branches with the trunk. When the angle is wide, as in Figure 24, there is a fairly strong knitting of the tissue at the top of the union, a continuous layer of new wood — points 2, 3, 4, 5, and 6 — being laid down each year; but when the angle is more narrow, this layer of new wood is sometimes discontinuous and weak, as shown at points 3, 4, and 5 in Figure 25; while if the angle is very narrow, there is no knitting of the tissue across the top, the bark

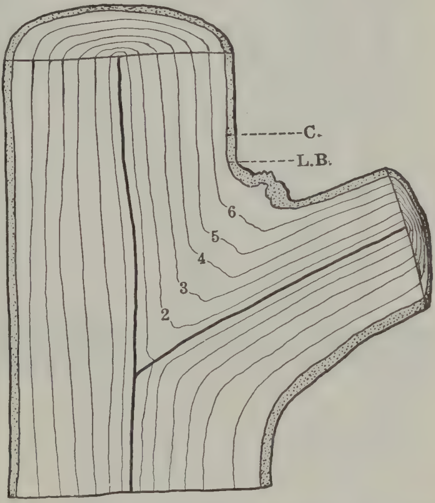

FIGURE 24. A crotch with a wide angle. The drawing shows the relative thickness of the successive annual layers of wood laid down by the cambium in the crotch angle, and also the irregular convolutions of the cambium layer, *c*, and the live bark, *L.B.*, at this point. (After MacDaniels.)

of the branch and trunk being tightly pressed together and preventing cambial growth across the top of the union as shown in Figure 26.

However, the wideness of the angle does not seem to be the most important feature in determining the strength of the union. The size of the branch as compared with that of the branch or trunk to which it is attached seems to be more important. If the branch is attached to a larger, more rapidly growing trunk, the tissue of the trunk may grow around that of the branch in such a way as to make the union strong. In Figures 27 and 28 from MacDaniels (862) branches have been split out from the trunk. In Figure 27 the tissue of the branch was rather strongly imbedded in that of the trunk and was broken out only with difficulty, while splitting down was very easy with the union shown in Figure 28.

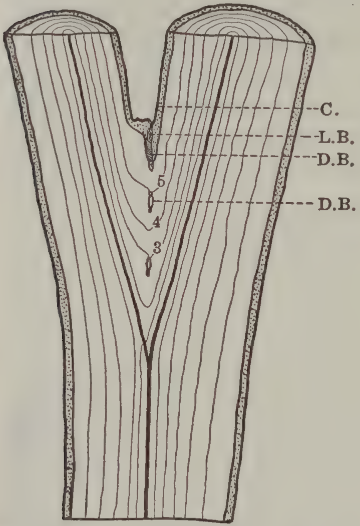

Figure 25. A narrow crotch. In this case the bark of the side arms in the crotch angle comes together before the crotch angle is filled with woody tissue. The result is that parts of the bark (*D.B.*) are squeezed off and become embedded in the wood, thus weakening the crotch union. (After MacDaniels.)

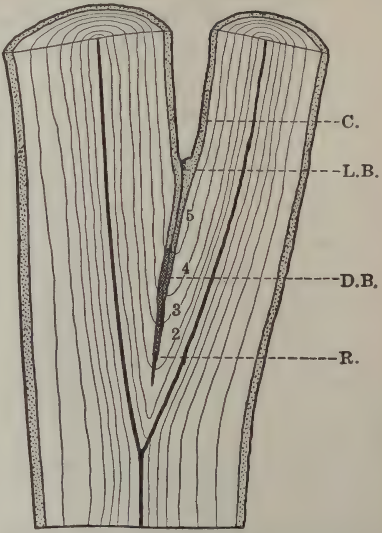

Figure 26. A crotch with an extremely narrow angle. The wood in the crotch angle is everywhere separated by bark, which near the point of insertion is rotten (*R.*). This grades into dead bark (*D.B.*), which gives place farther up to living bark (*L.B.*). A crotch of this type is practically sure to split. (After MacDaniels.)

The form of tree that gives the strongest union is what is known as a central leader, by which all of the branches are suppressed by pruning except a central upright stem, to which all of the branches are attached. If there are a considerable number of branches attached to this leader, it will tend to grow around the branches at their bases in such a way as to form very strong unions. Very much pruning is required to obtain this form for most kinds of fruit trees; and the delay in fruiting thus caused may be too expensive. However, with some varieties of apples and a few varieties of pears it is desirable. It seems best, therefore, to discuss it more in detail in Chapter 19 under the pruning of the apple.

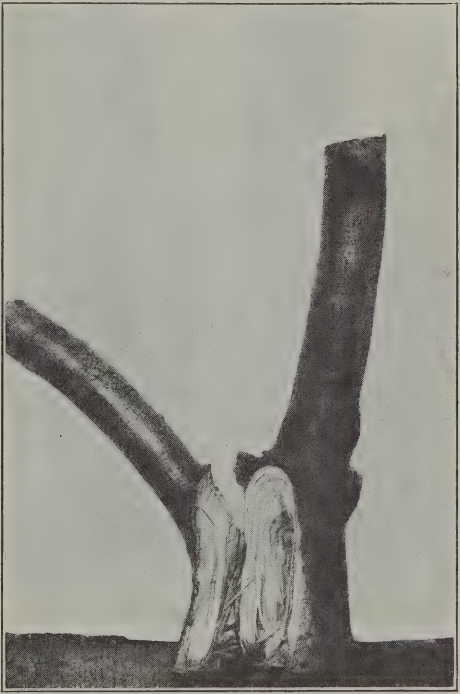

FIGURE 27. It required great force to break this union, the branches being uneven in size the tissue of one is embedded in that of the other. (After MacDaniels.)

With trees of nearly all varieties of all kinds of fruit the union may be sufficiently strong with the system sometimes called the modified open head or modified leader, by which the uppermost branch is kept the largest but is permitted to assume its natural form, growing outward or upward in accordance with the variety characteristic, but being trained outward after it begins to bear heavy crops. Two branches coming from about the same level on the trunk but from opposite sides may do no harm; but others should be a foot or more apart up the trunk. McDaniels found that with many branches coming from the same level there may be little or no knitting of the tissue of the different branches, but a very sharp cleavage and little strength; and with some varieties, such as the Agen prune, there may be a rotting down the center of the trunk as a result of such a thick clumping of the branches. If any but the uppermost branch is permitted to become much larger than the others, a stage may be reached when the trunk will split easily.

Of course, it requires pruning of the other branches to keep the uppermost one the largest; and, with trees like those of the apple, which become very large — unless they are planted rather close and are to be pruned rather severely when they have reached heavy bearing — it seems best to give at least that much shaping; with many kinds it seems better to do little pruning to shape except to remove all but three or four main branches and to brace these with wires before the tree is old enough to bear crops that would split down the branches. However, such a system would probably work well only with trees that are not permitted to grow exceptionally tall after coming into heavy bearing.

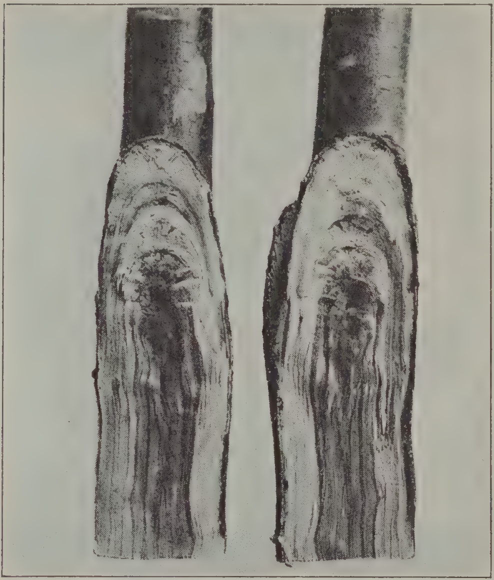
Figure 28. The branches are of the same size and are easily split apart. (After MacDaniels.)

After trees have come into heavy bearing the unions seem to become stronger as the trees grow older; and so there seems to be less splitting-down of branches on old trees than on trees just coming into heavy bearing. Just why branches of rather old trees should have greater strength of union relative to their size than have younger trees is not certain. It may be due partly to an infiltration of gums in the older wood — "heartwood" — and partly to an interknitting of the tissue at the unions due to the fluctuating growth of the branches relative to each other. Of course, if, after the trees have come into heavy bearing, the branches are pruned back to about the same length each year, the strain on the union is not increased appreciably from year to year; and yet, due to the growth in diameter of the trunk and of the branch at the base and to the greater strength of old "heartwood," the union is growing much stronger.

Renewal pruning of older trees. We have seen in Chapter 15 that the trees of most kinds of fruit, if not of all kinds, reach a condition when renewal pruning prolongs the life of the tree and certainly increases the size and probably the amount of fruit borne; this by keeping the tree in a more vigorous condition. Even if renewal pruning were not desirable for that reason, the tree — except when planting distances are very great — reaches such a size that it cannot spread more and can only grow upward and thus increase the labor of harvesting and of other operations. We have seen in this chapter that, while the greatest invigorating effect may, under some conditions if not under all, be near the point where the cut was made, cutting away any part of the tree, in the dormant season at least, seems to increase the vigor of all parts. It would seem wise, therefore, to leave as much as possible of the shaping of the tree for this time, when a considerable amount of pruning is desirable for its invigorating effect. It has been made clear that the removal of many branches that must eventually be cut out may well be left until this time, the exceptions being branches that would tend to cause weak crotches, centrally located branches that, left so long, could not be sawed off so close but that stubs would be left to rot into the trunk, and fairly vigorous lower branches so close under permanent branches as to weaken them by impeding the supply of nutrients moving to them. Certainly, much of the cutting-back necessary to suppress one branch in the interest of another, such as the uppermost branch, can often be delayed until this time, and much of the pruning to give desirable form to individual branches. Of course, if a central leader form is desired, the tree must be trained to that from the beginning.

In renewal pruning there is a nice question as to how the cutting (aside from the removal or modification of branches from trees with which that removal or modification has been deferred until renewal should have become necessary) shall be done. With some kinds — as, for example, the peach — it has generally been the custom to shear the trees back rather evenly, the longer twigs being cut to stubs, often very short, but generally about one third to one half of their original length; the shorter twigs generally being cut to a smaller extent. Peach trees in most sections were sheared to rather even round tops, though in some large growing sections the trees were sheared nearly flat across the top. A similar system, known as the "Winter's System," by which the trees were cut back to broad flat heads with the outgrowing branches much longer than the upward growing ones, was practiced with apricots in California (Tufts 904). Good results have been obtained by the shearing back practice, and we have no conclusive experimental evidence that any other practice is better. However, such heading-back of the twigs has three disadvantages. It is very laborious; it may cause most of the healthy growth to be at the outer ends of the branches, that lower on the branch tending to be shaded off; and, as practiced by many growers, the trees cannot be kept at a given height, but tend to become about as much taller each year as the length of the twig stubs left in pruning. Lately in some sections some of the more dependable growers have come to prune in ways that require less work and seem to give as good or slightly better results.

The system followed is generally one by which a branch is cut back to a lateral branch. Often one piece removed by one cut will contain a considerable number of twigs, cutting back of each of which would, by the older method, have required nearly as much labor as the cutting-off of the larger branch part. By this system, as practiced by growers in New York, branches are cut back only when, in the grower's judgment, they are tall enough or weak enough to make cutting-back desirable; not all branches being cut back each year. Of course, if any part of the head seems too thick, it is thinned out; the thinning, however, being — as far as possible — a cutting-back of branches to lateral branches rather than a cutting away of branches. By this system of renewal, which might be called thinning-back as compared with shearing-back, there is less shade in the tree and less injury to the fruit from crowding against other branches or stubs, and less dying back of stubs and rotting into the branches or the trunk. However, in some sections with some fruits annual cutting-back of twigs may be necessary. In California a system of thinning-out, and cutting back to other branches, has come to be called long pruning, this term being used because whole twigs were generally left instead of a larger number of twig stubs. Of course, much more pruning is necessary in the sunny climate and long seasons of California than in the cool humid climate and shorter seasons of New York. Experience has indicated that under conditions in some of the fruit sections of California this long pruning must be modified, at least for some fruits, the crops of fruit set being too large and the fruit being small even when it is thinned carefully. With these kinds it will be necessary to cut back some of the longer twigs; and, in some cases, it may be found best to do more cutting-back of twigs and less thinning-out of branches, the cutting-back being severe enough to insure large size of the fruit.

Under nearly all conditions, if not under all conditions, renewal pruning will keep a tree smaller than it would be without such pruning. In fact, the invigorating influence of pruning seems generally to be present to any marked extent only during the summer following the pruning; and, if the tree is to be kept permanently at a state of vigor above that of unpruned trees, it must be pruned annually. In other words, the tree must annually have some of its excess fruit buds removed in pruning and have its top reduced relative to its root system. And the reduction in the top reduces also the root system. However, the cutting away of wood and reducing the distance through which water and nutrients must move seems to have some influence on the vigor of growth, and this influence may continue more than one year; under special conditions possibly a number of years after a single pruning. As a result of an occasional year in which conditions are so unfavorable that growth is checked very early and very poor wood is formed — perhaps of a kind with very low efficiency in conducting water or nutrients — cutting back the branches and thus removing such poor conducting tissue might have such an influence. Under such special conditions a pruned tree might grow enough more rapidly to overcome the dwarfing effect of pruning and to become larger than would such injured trees unpruned. I think I have seen such results with peach trees, though environmental conditions were not studied carefully enough to justify conclusions. There is need for a study of the effect of pruning on the ability of the tree to conduct water and nutrients, particularly of the problem as to whether or not poor conducting tissue, if there is such, formed in an unfavorable year, may weaken a tree during several years unless it is removed by renewal pruning.

It seems certain that, if the injury from unfavorable environment were annually present, pruning could not increase vigor without reducing the size of the tree. For, if pruning did not reduce size, it could not improve the conditions for growth of the parts left. For example, if water conduction were inadequate and pruning should increase conduction temporarily and thereby increase growth and leaf surface, it would increase transpiration, accentuate the deficiency in water supply and reintroduce the poorly developed conducting wood. But, if the water supply were so low only once in 4 or 5 years, pruning back the weak wood following such a year might — by causing the growth of better conducting tissue — increase growth during several succeeding years, if the soil water supply should continue to be adequate. If the invigorating effect of pruning should be due to a narrowing of the carbohydrate-nitrogen ratio, pruning could not merely by changing the chemical composition of the wood cause permanently increased growth. For, if it were limited soil water or nitrogen that caused the accumulation of carbohydrates, then pruning could appreciably influence that condition only by reducing the leaf surface or the number of growing points relative to the supplying power of the roots — that is, by reducing the size of the tree.

Effect of top-working on fruiting. The practice of top-working, using buds from desirable strains, is recommended for the Washington Navel orange orchards in California. And with most kinds of fruit growing top-working trees of undesirable varieties to desirable ones is necessary. Top-working is practiced also in order that trees of a variety susceptible to some injury, such as pear blight or winter freezing, may have resistant trunks. It is well to emphasize the fact that, since pruning markedly dwarfs young trees and delays fruiting, and since top-working trees involves rather severe pruning, we cannot hope to top-work a tree without reducing fruitfulness for a time. Of course, if the scions are of a more productive variety, the reduction in fruitfulness due to the pruning involved in top-working may be very quickly offset by the greater fruitfulness of the new variety or strain; but the fruiting will for several years be less than if the tree had been started with that strain. The younger the tree is top-worked, of course, the less will be the amount of wood cut away and the less will be the amount of dwarfing and of fruit lost. The practice of budding on the branches during the first summer after planting will generally result in the least dwarfing. Even this, however, causes some reduction in growth and early fruiting. At the Cornell Experiment Station, of two adjacent rows of apple trees, one was of Twenty Ounce top-worked on Northern Spy, the trees being set in the spring of 1911 and budded in the branches in August, 1912. The other was of Twenty Ounce trees set in the spring of 1911. Not only were the top-worked trees delayed by the direct effect of the pruning necessary to top-work; but, on account of the thick upright growth of the top-worked trees, more pruning later was required. The average tree planted as Twenty Ounce had yielded by the time it was ten years old 418 pounds, while the average tree started as

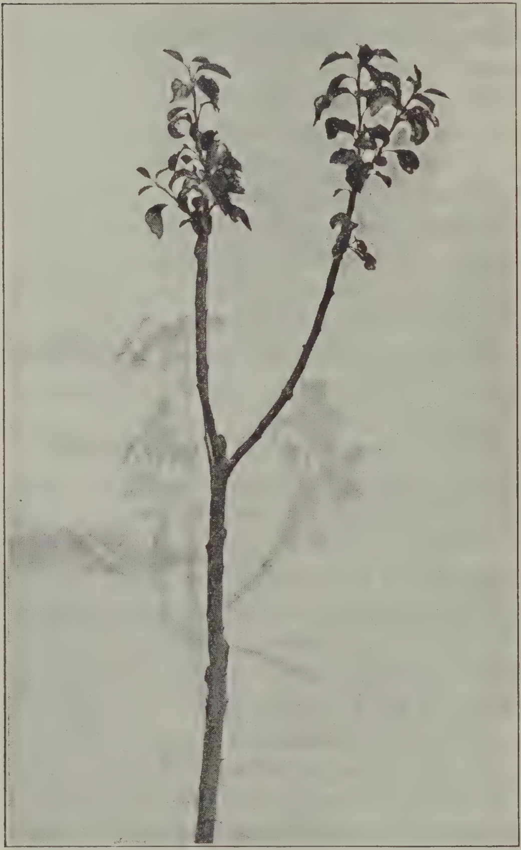

FIGURE 29. Young apple tree top-worked by whip grafting on the twigs in the spring of planting. There is practically no reduction in size due to the top-working, since it is cut back little if any more than it would have been for transplanting.

Northern Spy and top-worked to Twenty Ounce had yielded 392 pounds. This probably represents the minimum loss that may be expected from top-working by any method that is commonly practiced. Two Northern Spy trees in this same planting were not top-worked until the spring of 1917. Necessarily most of the top was cut away at that time. The total yield from these trees by the time they were ten years old was 16.7 pounds and 14.1 pounds. It is certain that for many years these trees will yield less than if they had been Twenty Ounce from the beginning and less than if they had been top-worked while younger.

There is a method of top-working that, under some conditions, may be used, if branched trees are planted, that will dwarf the tree and delay fruiting little if any. It is to whip-graft on the twigs in the spring soon after the trees are planted, where trees two years old are used. An example is shown in Figure 29. By this method the trees will be cut for top-working no more than the necessary cutting-back for transplanting. The use of this method not only eliminates most of the dwarfing, but it tends to give a better form to the tree. There is not the thick upright growth that is caused by the cutting-back where top-working is done after the tree is well started. And the graft is set far enough out on the branch for the crotch to be of the resistant stock. In so far as I am aware, however, the method has been tried only in a small way and only with apples in the rather humid climate of New York. While in that experience the results were excellent, it is possible that with most other fruits and with the apple in less humid climates the results would not be satisfactory.

Root pruning. The cutting of the roots of trees is generally discussed under pruning. It, of course, forms no part of the regular training of the tree, but is done for the same reason that seeding down to grass or ringing may be done, that is, to reduce the water or nitrate supply and increase the carbohydrate concentration, thus encouraging the setting of fruit buds. Root pruning, in its influence on the tree, is the reverse of top pruning. When the roots are pruned, top growth is checked and, due to the accumulation of organic food, new root growth is probably rather rapid until, by increased root growth and reduced top growth, the normal balance between root and top is reëstablished; while when the top is pruned, root growth is reduced and top growth more vigorous until the balance is reëstablished. Drinkard (806, 807) gives the results of some root pruning experiments which demonstrate that with young trees fruit-bud formation can be greatly stimulated by such a practice. It does not necessarily follow, however, that the practice would be profitable; for, as Drinkard's results show, the excessively heavy crop the year after the root pruning is generally followed by a year with little or no fruit. Further, the tree will eventually be smaller on account of the practice; and this will of necessity reduce the possible annual fruiting. Root pruning is of practical importance only under conditions where it is desired to keep trees small. Except in sections where the growing seasons are so short that rather severe pruning will prevent fruit-bud formation, thinning-back of the top by the method described in this chapter will accomplish the same result and will increase the vigor of the tree, which vigor root pruning reduces.

Considerable amounts of root pruning may be done in cultivation. When an orchard that has been in sod is cultivated, much root cutting is of necessity done. It is not possible to say that this does no harm, but abundance of experience indicates certainly that the benefit from the ploughing is so great that the effect of the root cutting cannot be detected. We have seen that the root system in a sod orchard is much larger in proportion to the size of the tree than that in a cultivated orchard; and so it is possible that this root cutting does not reduce the root system so much but that it is able to supply water and nitrogen enough for vigorous growth, the water and nitrate supply in the soil having been increased markedly by the cultivation. One is generally advised to plough such an orchard very shallow. I do not know of any experience, however, that indicates with certainty that even deep ploughing with the additional root cutting would be injurious. Cutting of the roots by the plough leaves many stubs near the surface from which new rootlets may grow very rapidly into the newly worked and better aerated soil; while pruning the roots close to the tree may remove a main root with all its branches. Replacement of such a loss will be much slower than replacement of the smaller roots cut in ploughing.

Pruning wounds. Sorauer (900) has described the means by which the tree covers a wound. The callus that pushes over the wound is made up of very large irregular cells; the form being due to the removal of pressure on meristematic cells. Later there develops a bark and cambium over this callus, the wound eventually being entirely covered, and normal phloem and xylem and other tissues being formed over it.

This is not the first protection that the tree forms against drying out or decomposition of the exposed wood. According to Higgins (830), when any injury occurs to the wood, there is rather abundant gum formation. With trees of the genus *Prunus* this quite commonly exudes in considerable masses. It is very general with trees. He found it with *Prunus*, *Pyrus*, *Juglans*, *Corylus*, and many other genera. He seemed to find that this gum is formed from the pectin in the cell walls. At any rate, soon after such an injury occurs, a pectin-dissolving enzyme was found to be present in considerable quantities. His evidence suggests strongly that the activity of the enzyme is increased by a slight drying out. When the wound was covered there was little gum formation; and wounds exposed to very dry air formed gum more rapidly than those in a very humid air. Thus, it seems that with many species the tissue itself tends to plug wounds with gum which may serve as a protection against drying out and against injury from parasitic organisms.

Keil (845) studied the healing of a very large number of pruning wounds. As would be expected, wounds healed most rapidly on the vigorous, healthy branches, in locations where new sapwood was being laid down rather rapidly. Wounds cut close to a branch or trunk healed much more rapidly than those at the end of a branch that was cut back. Howe (833) found the wounds to heal more rapidly when the branch was cut very close to the trunk or branch from which it was removed. It is well known that the branch expands rather rapidly at its base; and so, if it is cut as close as possible to the trunk or branch, the wound is much larger than if one starts the saw against the trunk at the top, but lets it go through the branch slanting outward from the trunk, so that at the lower side wood left from the branch will project one half to three fourths of an inch. Howe's observation that the wounds made by cutting closest to the trunk heal most rapidly would hardly justify one in concluding that the wound should be made much larger by cutting parallel with and against the trunk or branch from which a branch is removed.

Keil seemed to find the wounds to heal considerably faster when the pruning was done during the growing season than when it was done during the dormant season. Of course, the rate of wound healing would not be of enough importance to make it a determining factor as to when pruning should be done.

Coverings for wounds. It is generally recommended that wounds be painted with some covering such as white lead or zinc paint, coal tar, or asphaltum, the purpose being to prevent the activities of wood-destroying organisms. Howe studied the effect of white lead and white zinc paint, yellow ochre, coal tar, shellac and avenarius carbolineum on the healing of wounds of peach and apple trees; and Keil studied the effect on apple tree wounds of dressings of asphaltum mixed with linseed oil, asphaltum mixed with a low grade kerosene, and white lead paint. Both found that the healing of wounds is appreciably delayed by any dressing used except shellac used by Howe. Keil found white lead paint the most durable of the substances that he tried, and Howe found white lead and zinc paint more durable than the others. He found coal tar a very poor dressing, because it remained on the wound for such a short time. Volk (912) seemed to find that any paint is ruptured by the pressure of the water underneath; and, since the paint prevents the drying-out of the wood, conditions at the ruptured spots in the painted surface are more favorable for the entrance of a wood rot fungus than is the unpainted surface.

Drinkard and Ingham (807) studied the effect of white lead paint, of a commercial preparation called Nu-tree, of North Carolina pine tar, and of grafting wax on the healing of wounds made in ringing, and found all except grafting wax to kill the cambium back under the bark, thus enlarging the wound. Grafting wax did not kill the cambium, but it seemed to delay the growth of the callus. Volk seemed to find a wax made of eight parts, by weight, of asphaltum and two parts of paraffin harmless to the tissue and a very durable covering.

Young (920) seemed to find sodium silicate (water-glass) a very effective coating for wounds. It is soluble in water and seems to penetrate into the tissue at the cut surface better than do other wound dressings. Oxidation at the surface seems to cause the deposition of a layer of insoluble silica that is strong enough to prevent "bleeding" from the wounds, even with the silver maple and varieties of Rotundifolia grapes; yet no injury appeared in the surrounding cambium. Such a layer should be very effective in preventing the entrance of organisms. Young is studying the possibilities of combining the water-glass with compounds of copper or other heavy metals or with mercuric chloride, in order to obtain an antiseptic deposit at the surface of the wound. This might prevent the entrance not only of the common saprophytic organisms that cause the rotting of the heartwood, but also of virulent parasitic diseases such as gummosis, pear blight, and various other canker-forming organisms. Bordeaux paste is now often recommended as a protection against such organisms.

The thoroughness with which wounds of all sizes should be covered will depend upon whether or not one of these virulent diseases is prevalent. When only saprophytic organisms are to be considered, small wounds, let us say two inches in diameter, may well be left without coverings, since heartwood-destroying organisms will not become harmful before the wounds will be naturally covered. In fact, in most sections very few growers have ever practiced painting such small wounds. One would not be justified in saying that painting is undesirable in case of large wounds, merely because the healing is slightly delayed by most dressings. However, the rotting of the wood generally will not begin for several years after the pruning is done, and since no covering, unless it be that formed from application of sodium silicate, will remain for more than a few years, it seems wise to delay the painting a year or two, so that the callus may be well covered by a protecting bark. Thus, except in sections where virulent diseases such as cankers are prevalent, all the benefit of the paint would probably be obtained without the harmful effect of paint on exposed cambium. However, in the Pajara Valley of California, in the cool moist air, the oyster shell fungus seems rapidly to injure the tree through any uncovered wounds; and disinfecting new wounds with a solution of one part of mercuric chloride to 1000 parts of water, followed by a coating of hot asphaltum (grade D), is recommended by plant pathologists, without their having made an exhaustive study of the specific problem.

Tree surgery. Closely related to the covering of wounds is the filling of large wounds in old trees. When the heart of the old tree is badly rotted, even if it does no other serious harm, it greatly weakens the tree so that it is liable to split or break under a load or in the wind. With ornamental trees, it is the practice to fill these large cavities with cement after the dead wood has been chiseled out; and many fruit trees are so treated. Sometimes a disinfectant, such as Bordeaux paste, or a covering like tar or asphaltum is spread over the inner surfaces before the filling is put in. It is generally customary where the cavities are large to fill in the center with stones, so as to reduce the amount of cement required. Next to the walls of the cavity and the outer surface should, of course, be of a mixture rich in cement. Selby (894) has described a material for filling such cavities that is made of one part of asphaltum and three or four parts of sawdust. The sawdust is stirred into hot melted asphaltum until the desired consistency is reached, and the material is applied in the cavities while still hot. It is claimed for this mixture that since it has more elasticity than has cement it may be more desirable for use in swaying trees.

Whether or not it would be profitable to preserve trees in an orchard either with the cement or with the asphaltum filling would depend upon the condition of the orchard generally. Since trees would seldom be found with equal degrees of injury, and the variation in yield of such old trees would be very great, it would be very difficult to determine the value of such treatments experimentally. There seems little doubt, however, that the tree can be made stronger and the rotting of the trunk reduced or prevented; and so for locations where orcharding is profitable, there seems to be little question as to the wisdom of such practice.

Summary. Cutting-back the branches increases the thickness of the head of a tree and tends to increase the amount of shoot growth and the shoot leaf surface, greatly reducing the amount of spur leaf surface. It causes a tree to stand more rigidly against a continuous wind. Thinning-out may tend to increase the length of individual shoots; but it reduces the total amount of shoot growth by reducing the number of growing points. It reduces the amount of spur leaf surface somewhat less than does cutting-back. As to which dwarfs the young tree the most, we have no conclusive data. Probably thinning-out dwarfs a bearing tree more than does equally severe cutting-back, since thinning-out does not prevent excessive fruiting on the branches left. With young trees both cutting-back and thinning-out should be done only when there is a very specific need for such pruning. If lower branches that must eventually be cut out but that temporarily are not injurious to any permanent branch are left for a number of years, they may bear some fruit and contribute to the growth of the remainder of the tree; provided they make less vigorous growth than do the permanent branches. Branches that grow very rapidly relatively to the permanent branches should generally be removed as soon as it is known that they must eventually be removed.

When individual branches are pruned, and the remainder of the tree is left unpruned, the dwarfing effect on such branches is much greater than would be the dwarfing effect if the remainder of the tree were pruned as severely. With trees bearing fruit buds to the ends of the branches, cutting back and thus removing many fruit buds invigorates indirectly by reducing the depleting effect of setting excessive numbers of blossoms and young fruits. Such an invigorating effect seems to be localized.

In some way, growth at the apex of the branch inhibits growth of buds or shoots back of the apex. This polarity is much stronger with some varieties than with others, and is of importance in pruning trees. In the case of figs and some other fruit trees, polarity is so strong that only a few buds near the terminal of a twig grow; and so, if a twig of a fig tree is cut back, as many shoots grow from it and the leaf surface is not reduced, the only dwarfing effect of the pruning probably being due to a thicker head with more shade. When a branch is cut close to the trunk or another branch, growth of the shoots above seems to inhibit growth from dormant buds around the wound, except on the lower side, and few or no "water sprouts" are formed; while if a stub — perhaps six inches or more in length — is left, such "water sprouts" form, dormant buds being near the apex of such a stub and the inhibiting influence from the branch parts above not moving out along the stub. Bending a branch downward changes its polarity, often causing the strongest shoot to grow far back of the terminal near the highest point on the curved branch. Bending less severely seems to cause better growth from shoots and spurs toward the base of the branch, although the strongest growth continues to be made from the terminal shoots. Severe bending of branches hastens the fruiting of young trees and probably dwarfs them, at least by means of the early fruiting and by causing the strong growing shoots to be crowded within smaller space. As to whether or not less severe bending hastens fruiting or dwarfs the young tree, we have no data.

The strongest unions of branches are obtained when the branch approaches the trunk at a rather wide angle and when the trunk is considerably larger than the branch, so that the tissue of the trunk tends to surround that of the branch. As the tree grows older the union of the branches to the trunk seems to grow relatively stronger. If the tree can be brought to the age when it begins to respond profitably to renewal pruning, much of the necessary shaping can be done after that time, probably without reduction in fruiting.

In renewal pruning cutting back mainly to secondary branches seems to be preferable to shearing back because the work can be done much more cheaply and better results seem to follow; though when there are very long twigs bearing fruit buds — with some varieties at least — these should be cut back individually. The amount of renewal pruning that trees will need will depend upon the characteristics of the variety, the nature of the soil, the water and nitrogen supply, and the planting distances.

Top-working trees entails a considerable amount of pruning; generally more the older the trees are when the top-working is done. With apple trees in humid climates whip grafting at the time the trees are planted may be a means of avoiding the dwarfing effect of much pruning in top-working.

Root pruning is the reverse of top pruning, top growth being weakened until by increased root growth and reduced top growth the original balance between root and top is established. With over-vegetative trees the checking of growth resulting from root pruning tends to increase fruit-bud formation.

Most coverings for pruning wounds tend to injure the cambium and delay callus formation around the wound; but sodium silicate, common grafting wax, and a mixture of paraffin and asphaltum do not; hot asphaltum may not. With large wounds, however, or with any wounds on trees where virulent diseases, such as blister canker of the apple, are prevalent, it may be wise to use a covering that is also a disinfectant, even though healing of the wound may be delayed.

CHAPTER 18

PRUNING AND TRAINING THE TREES OF THE DIFFERENT KINDS OF FRUIT

The apple. So much of the data discussed in the three preceding chapters was secured from apple trees that not all their peculiar pruning responses need be discussed in this chapter.

The blossoms of most varieties of apples and of pears are on the terminals of spurs or of short twigs; and cutting-back trees reduces the number of spurs and short twigs (782, Gardner, 813) considerably more than it reduces the size of the tree. Cutting-back, therefore, tends to cause a greater reduction in the amount of fruit borne by young trees with such varieties of apples and pears than with other fruits. However, some varieties, such as Wealthy, Oldenburg, Jonathan, Rome Beauty, Wagener, Winter Banana, Rhode Island Greening, and Golden Delicious, tend to bear many lateral fruit buds on the shoots, the larger number being toward the apex of the shoot, and more being formed on very vigorous long shoots than on shorter ones. If it were possible to stimulate such strong shoot growth without cutting back the shoots enough to remove all of these lateral fruit buds, cutting-back might not reduce the fruiting of young apple trees forming such lateral fruit buds, more than it reduces the fruiting of other kinds such as the peach and the apricot. But generally, if the cutting is severe enough to cause the growth of such vigorous shoots, the twigs must be cut back of the section where lateral fruits are generally found; and, if some of the twigs are left unpruned to bear fruit, they will tend to prevent the growth of vigorous shoots from the twigs that are cut back. In the Cornell University orchard the reduction in fruiting of young trees caused by their being cut-back is greater even with Oldenburg and Wealthy apples (varieties forming many lateral fruit buds) than with other fruits such as some plums. Naturally, since cutting-back reduces the fruiting more, it tends to dwarf young bearing trees less with the apple than with some other fruits, though not less than with the peach.

Thinning out branches of young apple trees does not seem to cause many spurs to grow into shoots on the branches left; the branches left bear as much as they would without the thinning out; if not a little more. The reduction in fruiting following thinning out the branches of young apple trees may be, therefore, approximately in proportion to the reduction in the size of the tree.

In the northeastern part of the United States many growers formerly cut away the lower branches on a tree each year until the first branches were four to six feet high. It is needless to say that such pruning dwarfed the young tree. Howe (834) found experimentally a very striking reduction in growth caused by training young apple trees to heads the lowest branches of which were four feet from the ground. In that northeastern section the other training given young trees was each year to remove all branches that seemed likely eventually to become undesirable. The head of the tree was thus kept very thin and open. That pruning coupled with the training to rather high heads dwarfed to such an extent that trees fifteen to twenty years old or older bore no more fruit than they should have borne when ten years old (782). The delayed fruiting of high-headed trees was due mainly to the pruning, but also to the fact that young trees with high heads suffer more injury from being blown about by the wind. In fact, it is generally necessary to fasten them up to stakes. However, young trees with the lowest branches twenty-four to thirty-six inches from the ground are of a convenient height and do not show much more of such injury than is shown by lower trees; and, if the young trees in the nursery are headed that high and no pruning away of lower branches is necessary after the tree is planted, there will be no delay in fruiting as compared with trees having lower heads; and I can think of no advantage of having the heads start lower. Yet some growers cut away at planting nearly all the top of trees two years old. While such pruning will cause less reduction in growth and early fruiting than will training to excessively high heads, it will probably cause some reduction; and the new branches from the stub left are liable to be injuriously crowded, thus necessitating additional pruning.

Vase form. It seems desirable here to describe in more detail forms discussed briefly in Chapter 17. The open head or vase form seems to have been borrowed from the French (Du Breuil, 808, and Hardy, 824). Du Breuil recommends that trees for this form have about twenty branches; not all starting from the trunk, however. Five would start from the trunk, from each of which two branches would be obtained and from each of these two more, thus giving the twenty branches. In the French gardens, branches were sometimes trained over a hoop, in order to give a symmetrical spreading head. In America the open head tree has been adapted to conditions where such laborious pruning would not be possible. Generally three branches were used, and these were kept about equal in size. If one branch obtained the ascendency, it was cut back.

The secondary branches were generally pruned in such a way that each main branch would serve as a central leader for the secondary branches; though, sometimes, each was caused to form two equal branches. This system was used more in California and the Pacific Northwest than elsewhere in the United States. Since the branches were not spaced on the trunk, and were all of the same size, the crotches were sometimes rather weak, and bracing by means of cross wires or otherwise was sometimes necessary. Some have recommended starting the tree with a central leader and later cutting the leader back or directing it outward simply as an uppermost branch. In the experiments at Cornell University, with the modified open head there was no effort to have an upright growing leader but the uppermost branch was kept the largest, and was permitted to grow upright or in a spreading form in accordance with the nature of the trees of the variety. If it grew upright, it was assumed that when the tree began to bear heavy crops it would be bent outward by the load. If it was not so bent outward by the time the tree was as tall as it was desirable for it to be, the uppermost part was cut back to an outward-growing lateral branch. The other three or four branches, spaced in accordance with suggestions in Chapter 17, were pruned back enough to keep the uppermost branch the largest, and the laterals on them were so pruned that each main branch formed

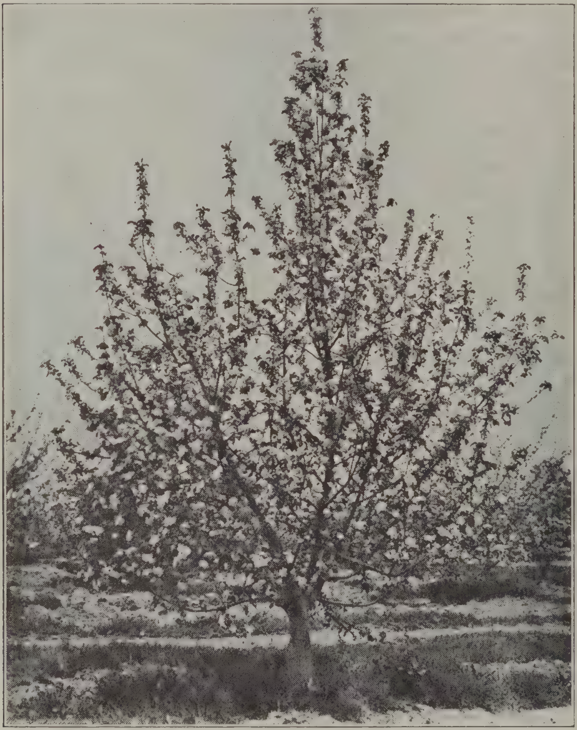

FIGURE 30. Wealthy apple tree pruned to a modified open head. Note that the uppermost branch starting from the trunk is kept the largest by being left unpruned; the others being pruned. This tends to cause the development of rather strong unions.

a leader for these laterals. We have seen that even this amount of pruning reduced the yields of the young trees.

Central leader or pyramidal form. Another old form, apparently borrowed also from the French, is the pyramidal, or central leader tree. Du Breuil says: "A tree trained in this form is composed of a vertical stem furnished from the top downwards to a foot above the soil, with lateral branches, the length of which should increase down to the base. Each lateral branch should have an interval of twelve inches between it and the branch immediately above, allowing the light to penetrate between them. They should be kept free from bifurcations and furnished with fruit branches alone, from end to end, and form an angle with the horizon of 25 degrees at the most." Du Breuil does not consider this form as desirable for the apple as for the pear. In America this system modified in accordance with economic conditions has been used perhaps as largely as any system by which the tree is trained to some definite form. Of course, it is evident that in America one could not afford to train the trees in such minute detail. It has generally been the intention of growers who use this system in America, by pruning back at the ends, to suppress the growth of all the branches, so that all will be kept much smaller than the central trunk. It is also generally the inten-

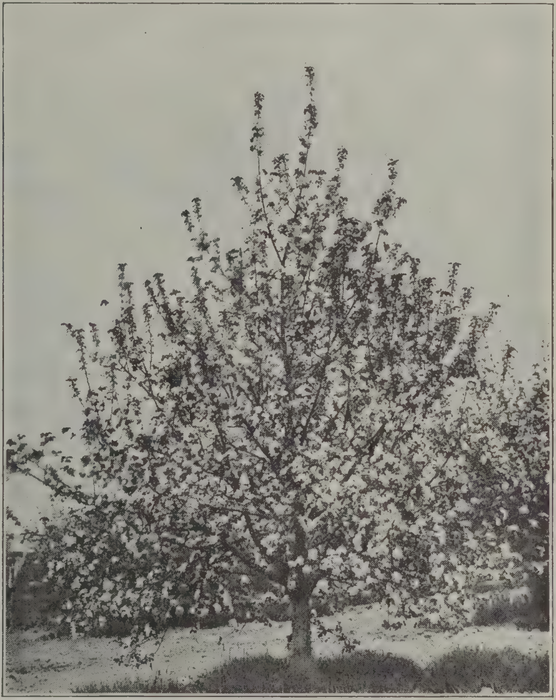

FIGURE 31. Wealthy apple tree pruned to the central leader form. Too many branches have been left; and the expansion of the branches at the base may be injurious to the development of the leader. There are too many branches near the same level on the trunk. With some trees of this kind in the Cornell University orchard the leader is being choked by such thick whorls of lower branches.

tion to prune back the upper branches enough for the lower ones to extend out farther than any above them and thus to have their foliage in the light. The tendency with many varieties, however, is for the upper branches to grow the more rapidly; and few, if any, growers prune them enough to avoid eventual shading out of the lower branches. Thus, if the tree is not dwarfed by excessive pruning to keep the upper branches the shorter, it is dwarfed by having many branches shaded out. Further, the shortening back of the branches necessary to maintain a leader tends to cause a rather dense growth. And one is liable to find, after pruning a tree to this form for a number of years, that a rather large amount of thinning-out of branches becomes necessary. Some varieties, such as Rome Beauty, Oldenburg, Wealthy, Wagener, Ben Davis, and Gano, are easily trained to this system. In sections where there is a considerable amount of loss from killing of the tissue in the crotch in winter, it is found that trees trained to this system show very little injury. This is probably due in part to the fact that the branches tend to approach the trunk at an obtuse angle and in part to the fact that there is less restriction to the movement of nutrients around the base of the branch. Northern Spy is a variety which, except for this crotch injury, can be grown in rather cold regions; and the trees of this variety are rather easily trained to the central leader form. On the other hand, trees of some varieties, such as Rhode Island Greening, Tompkins King, Baldwin, McIntosh, and many others, are trained to it only with great difficulty. With some varieties, such as Jonathan, the trees may be trained to this form while they are young, but there is a great tendency toward very rapid growth and much forking at the top of the leader after the tree is, let us say, twelve to fifteen years old.

A modified form of this system is known as the two-story tree. By this form a leader is maintained, and a system of four or five branches distributed around the trunk is left; then all branches are removed from the leader for a space of two or three feet or more, when another cycle of branches is permitted to grow. This obviates the fault of having the branches become too thick along the trunk. Since this system is farther than the more generally used pyramidal form from that which the tree would naturally assume, it will require more pruning, and cause greater dwarfing and greater delay in fruiting.

While with some varieties there is a tendency for lower branches to be weakened by the shade, there is with some, if not with all varieties, a tendency for a lower branch to weaken one above it apparently by reducing its connection with the supply of soil nutrients. With the pyramidal and the two-story form a whorl of lower branches too thick on the trunk may thus gradually choke out the part above, unless the growth of the lower branches is suppressed by pruning. In other words, to maintain a central leader or a two-story tree, it may be necessary sometimes to cut back upper branches to prevent their shading out lower ones, and sometimes to cut back lower ones to prevent their becoming too large at the base and intercepting the soil nutrient supply to the branches above; or to prevent a whorl of branches from becoming so large that they grow together and intercept the supply of nutrients to the leader and the branches above.

Natural form. Another form of training may be called the natural system. The only pruning given is to remove crossing and interfering branches, to correct forks by cutting back one branch, and to keep the branches thin enough on the trunk that all will have room to expand normally at the base. Of course, by this system there is no shaping of the tree, but it is left to assume its natural form. From what we have seen before, it is evident that trees pruned by this method will be more productive while they are young. In the pruning experiments at Cornell University there are, among other forms, trees pruned to the modified open head mentioned above, the central leader as it is ordinarily used in this country, and this natural system. The trees were planted in the spring of 1911 and the experiments began in the spring of 1914. That the trees of this natural form reached a profitable bearing capacity sooner than did those pruned to a modified open head was shown in Chapter 15. Trees pruned to the central leader reached such a bearing capacity sooner than did trees pruned to a modified open head but later than did trees pruned to this natural form. However, all the trees pruned to a modified open head were fairly good specimens of that form, while with Rhode Island Greening, Baldwin, McIntosh, Tompkins King, and some other varieties, the trees were not pruned nearly enough to develop a distinct central leader. It is reasonably certain that if all had been forced into a good central leader form, with few enough branches and those well enough spaced not to choke out the leader, very much more pruning, and consequently more dwarfing, would have been required than would be necessary to train trees to the modified open head. Of course, the pruning necessary to obtain any form might be desirable even though there was a considerable reduction in the amount of fruit borne during the first fifteen years in the orchard, provided that on account of such a form the trees would bear more profitable crops later. However, what meager evidence we have indicates that the fruiting of trees of maximum bearing size will be influenced very largely by the treatment they have at that time and very slightly by the training given when young, except for the proper spacing of branches on the trunk when the tree is planted or during the first two or three years. If it is desired to have an open head tree with the light reaching all parts, that condition can be obtained by pruning after the tree has reached such a size that the crop borne in any year is of more importance to the orchardist than the amount of increase in size of the tree and that renewal pruning is needed.

It should be said, however, in reference to the natural form, that in the Cornell University orchard more trees of that than of either of the other forms had branches split down from the trunk. It is more important with the apple tree than with most other fruit trees that there be strong unions and branches so disposed that they do not interfere with each other; for the trees live longer and the branches become larger than with most other kinds. It seems certain that enough pruning should be done to cause the branch starting highest on the trunk — forming, in fact, the continuation of the trunk — to be larger than the others at the base. It need not be upright in growth and it need not necessarily be the tallest. To be the largest at the base, however, it would have to have the largest leaf surface; and to maintain the largest leaf surface it would have to be the largest in spread or height or both. For, on account of the shading out, mere thickness of secondary branches on the main branch would not permanently maintain the largest leaf surface. Cutting away secondary branches from the main branches seems to be as effective a means of reducing their size as cutting back; and, if the lower secondary branches are cut from the main branches next to the uppermost branch, room will be left for a wider spread of the secondary branches of the uppermost branch. A little cutting-back or cutting-away of secondary branches from the main branches next to this uppermost one, so as to give it more room for the spread of its secondary branches, and a little cutting-back or cutting-away of secondary branches from any other main branch that is too near to becoming as large as the uppermost branch is generally all that is required to give a rather strong branching system, provided this uppermost branch has unintercepted connection through the trunk with the roots, no other large branch being directly below it.

Pruning apple trees at planting. Apple trees to be planted may be straight whips one year old from the bud or the bench graft. Generally, if they are more than twenty-four to thirty-six inches high, they are cut back to stubs twenty-four inches or more in height. If they were left as much as forty-eight inches tall, unless they were very strong, there would be blowing about in the wind and permanent bending after new shoots had started around the top. And the best shoots would be so high that it might be difficult to form a head at a convenient distance from the ground. In most sections, however, trees two years old are planted.

Such trees will have branches one year old (twigs). It is the custom to prune such trees rather severely at transplanting. While some growers do no pruning except to remove all twigs that are not wanted to form permanent branches, others cut back the twigs that are left. This last practice seems necessary in some climates at least, in order to reduce the early summer leaf surface to the capacity of the injured root system to supply water. With such injured root systems the amount of reduction in growth caused by pruning will probably depend upon the soil and climatic conditions. If the soil is so well aerated that a new root system will be quickly formed, and if the climate is one in which evaporation is not excessive during early summer, then even with a newly transplanted tree the more buds left, generally the larger the total growth will be, even though the growth from each bud may be very small. If, on the other hand, the soil is one in which the tree but slowly becomes established and the climate one in which transpiration is very high early in the summer, then rather severe pruning when the tree is set may not reduce the leaf surface for the tree throughout the summer and, therefore, may not reduce the growth of roots or tops. For, while there will be many more leaves to open on the unpruned tree, they will be very small and many may fall off. Certainly the time when pruning will cause the least reduction in growth of young trees is when they are first planted, the water-supplying power of the roots at that time being inadequate for a large leaf surface. And so, whether the branches are shortened or not, all crowding branches should be removed, for their removal then will dwarf less than if they are removed during the next two or three years. Thus, Pickering (872) found the fruiting of dwarf apple trees during the first five years greatly reduced by doing the pruning he considered necessary for young trees after they had been planted a year instead of doing it at the time they were planted. With some varieties grown in England, if the twigs were not cut back when the trees were planted and the branches were left unpruned during several years, fruiting while the trees were young caused severe injury. With standard trees that would not begin fruiting before they had overcome the weakening effect of transplanting, generally no such injury would follow. Card (778, 779) found no permanent bad effect either in the dry climate of Nebraska or in the humid climate of Rhode Island when apple trees were not pruned at planting time. And Cullinan (801), experimenting with trees growing in an exceedingly well aerated soil seemed to find pruning at planting to cause a considerable reduction in growth. In some climates at least cutting back the twigs left for permanent branches and thus reducing the initial leaf surface until the root system has become established seems to increase the chance of the tree to live. However, the problem has not had exhaustive study.

Some think that, since the terminal bud of an unpruned twig would open more quickly than would the lateral bud near the end of the stub of a cut-back twig, this greater initial leaf surface would increase growth. And some even think that leaving the terminal bud will in some way increase the probability that the twig will live. Leaving the twigs of cherry trees intact does have that effect, in some climates at least. However, we do not know how such an influence on the cherry tree is to be explained; and we have no conclusive proof that there is such an effect with apple trees. Cutting back the twigs when trees are planted seems to reduce the amount of pruning that will be required during the next few years, if the tree is to be trained in such a way that the uppermost branch will be the largest. If all of the twigs are cut back at planting but the uppermost one left the longest, while it does not always continue to be the longest, it will tend to do so; and little pruning may be necessary in later years in order to keep it the largest. On the other hand, if all the twigs that are to form permanent branches are left unpruned, there is often such a serious check that in the next year the largest growth is made not from the uppermost bud but from dormant buds or spurs near the base of these branches, or from dormant buds on the trunk; and these often grow more rapidly than any of the branches, including the uppermost one. This may necessitate rather severe pruning of the other branches in order to give the ascendency to the uppermost one. And in many cases the uppermost one may be the branch suffering the greatest check (see Figure 22, Chapter 17). With our present limited knowledge it seems that, while in some climates and with some soils leaving the twigs without cutting-back may result in larger growth and under many conditions there may be little difference, the safest procedure would be to cut them back at least thirty to forty per cent.

Trees that have reached heavy bearing. We have the results of no comprehensive experiments with pruning rather old apple trees. It has been shown in Chapter 15 that what meager evidence we have indicates that such trees will fruit better if given some renewal pruning; and rather severe pruning will not throw out of fruiting the spurs and twigs left. There will be more vigorous wood growth; and, with some varieties, the shoots at the end of severely pruned limbs may form branches instead of fruit spurs. That is, such vigorous shoots may continue in a vegetative branching stage, much as young trees do, for several years. However, with some varieties, such as Wealthy, Rome Beauty, Oldenburg, and Golden Delicious, in most climates, and with most varieties in some climates, these very vigorous shoots may form terminal fruit buds and many more lateral fruit buds than would weaker shoots. If such vigorous shoots do not branch profusely, their buds may form spurs that fruit younger than would the average spur from weaker shoots. Up to a certain degree, increase in severity of pruning may increase the tendency of the shoots to form axillary fruit buds.

Annual renewal pruning not only increases the tendency of weak trees to set fruit buds, but to an even greater extent it increases the percentage of the flowers to set fruit and increases the size of the fruit. With some varieties, such as Wealthy, Oldenburg, Rome Beauty, Jonathan, and Winesap, renewal pruning will be needed most largely for the effect on the size of the fruit; while with others it may be needed more largely for the effect on the fruitfulness of the spurs left. Since increased vigor can generally be obtained through pruning only by a reduction in the size of the tree, the practice should be to maintain high vigor in so far as possible by maintaining an abundant soil, water, and nitrogen supply, and to depend upon renewal pruning only in so far as that can be done without reducing the size of the tree below that which gives the largest well-exposed bearing surface to the acre. However, if the water supply for irrigation or from probable rainfall is limited, or if the soil is very shallow or poorly drained, in order to obtain larger fruit or better setting of fruit, it may be desirable by pruning to maintain the tree at a size considerably below that which would give the largest bearing surface.

Roberts (292) has suggested that, with alternate bearing varieties, pruning in the spring before the non-bearing year may, by causing some of the spurs to be too highly vegetative to set fruit buds, avoid the excessive crop in the succeeding year and perhaps cause annual fruiting. Pruning in the bearing year, however, might by cutting out much bloom enable the tree to set fruit buds while bearing a crop. It seems probable that with most varieties annual renewal pruning, if severe enough, might cause annual fruiting. But such severe pruning might reduce the bearing surface of the tree enough to be unprofitable even if it caused annual fruiting.

The above discussion concerned bearing trees receiving good care. In nearly all fruit-growing sections orchards are to be found that have been neglected. During times of prosperity for fruit growers, successful orchardists tend to lease or to buy these neglected orchards. Generally the most important problems connected with their management are with pruning, particularly if the trees have become very tall. It is evident that variation among such trees will be great; and conclusive experimental evidence almost impossible to obtain. The following brief discussion is given merely as indicating the present state of our knowledge.

Some growers report that by pruning such trees very severely they have caused them to die. We shall see in a later chapter that such severe pruning might result in the tree's going into the winter slightly less resistant to frost. It might, therefore, be killed by freezing; though there is seldom such danger if there are enough branches left to supply a fairly large leaf surface. With varieties that are very susceptible to cankers severe pruning seems to increase that susceptibility. Thus any considerable amount of pruning-back of old Ben Davis trees in the Mississippi Valley may result in their death within a few years from blister canker (*Nummularia discreta*). In the more humid regions, however, where such diseases are not so serious, there is abundant practical experience to indicate that old trees may be lowered as much as twenty or twenty-five feet, provided no branch is cut so low that no healthy secondary branches are left on it. With varieties resistant to canker, the same may be done in the dryer sections. Thus, I have pruned away as much as half of the tops of Jonathan trees in Missouri without the slightest injury from canker, though Ben Davis trees pruned no more, or even less, were soon killed.

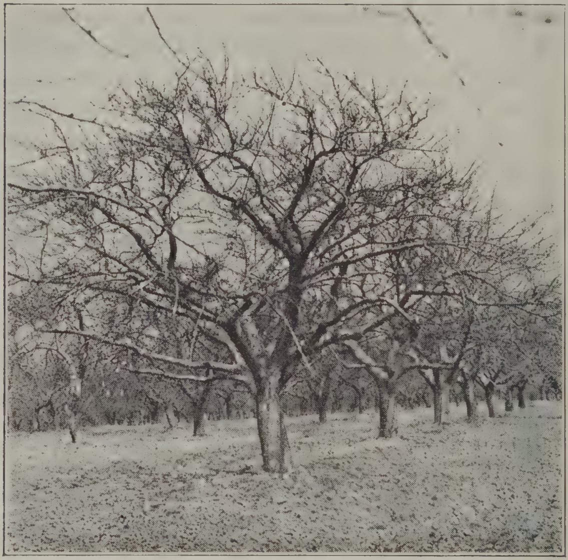

FIGURE 32. Old tree with long branches having most of the active wood at the terminals. Systematic renewal pruning would probably have given a more regularly productive tree; and one less expensive to handle.

Jarvis (838) and Ballou (751) seem to imply that, according to their experience, rather severe pruning of old trees has tended to stimulate the setting of fruit, though they describe no specific experiences. From being among growers in sections where many old orchards have received rather severe pruning, I have gained the impression that with such old trees the parts left are not thrown out of fruiting by the most severe pruning, and that the trees do not have their yields reduced in proportion to the reduction of the size of the top, but, in fact, in many cases the yields are actually increased. This increase apparently has resulted from increased size of the fruit and from such invigoration of weak shaded spurs that they have set fruit buds; or, perhaps more often, an increased percentage of the flowers have set fruit. Since we do not have available careful records of specific experiences, however, we cannot say how often such improvement in yield might be expected.

Where trees have been planted so closely that the lower growth is shaded off, it seems wise to cut no farther back than can be done and still leave healthy secondary branches. Later, the lower weak branches may be so invigorated by the pruning and other phases of good care that the branch may be cut farther down. If healthy secondary branches are not left, the branch either will die or will be clothed with water sprouts. These water sprouts eventually come into fruiting, but it requires a number of years; and as to whether rejuvenating an orchard can ever be profitable when water sprouts alone must be depended upon to form the fruiting wood, we cannot say from any satisfactory evidence.

Dwarf trees. The preceding discussion concerned the pruning of standard apple trees grown under conditions and practices such as prevail in the different fruit-growing sections of the United States. The work of Pickering, of Grubb (821), and of others suggests that it would apply also to many varieties grown as dwarfs. However, trees of some of the varieties selected especially for growing in sections where severe pruning is practiced might without such severe pruning bear fruit of a size and quality far below what the market developed for those varieties demands; and the practices of pruning twigs of certain length to certain buds and causing the formation of fruit buds at definite positions may be necessary for the production of the desired fruit in the particular districts involved. The rules developed from practice in one section do not necessarily apply in another section. Thus, Barker and Lees (754) found that in England the pruning advocated by Lorette for bush trees in parts of France was too severe for dependable fruiting. It is probable that where more severe pruning is practiced, adjustment of the severity of pruning to climatic conditions will have to be made very carefully, the pruning being more severe where the seasons are long or the temperature high than in sections where the growing seasons are short or the summer temperature rather low.

According to Du Breuil (808) the apple is better grown as a standard (by which he means a tree not fastened to a wall) than as espaliers, since most varieties of apples seem not to be adapted to the high temperature that will result from training against a wall. Waugh (915a) describes successful experience with training dwarf apples as cordons. Such practices seem to be profitable under economic and climatic conditions prevailing in some countries, and may be desirable in fruit growing for pleasure; and success in such training may involve very interesting application of scientific knowledge. However, they are of little importance to most people interested in the problems discussed in this volume, and the practices seem to have been developed largely from routine experience and dogmatic teaching rather than from experimental study. Methods of training to such forms are therefore not discussed here.

The pear. In its fruiting habit the pear so resembles the apple that only the ways in which its pruning response might be different from that of the apple need be discussed.

Du Breuil (808) says that, for most sections of France where standard trees are grown, the pyramidal form is best. Probably a larger percentage of pear varieties than of apple varieties can be easily trained to the pyramidal form. However, the thick growth of branches on trees of this form seems to make it more difficult to control pear blight (generally the most serious obstacle to successful pear growing), and in the large pear-growing regions of the Pacific Coast States of the United States the open head or vase form seems generally to be used, because it makes it easier to keep blight out of the trunk; and if one branch has to be removed there may be a considerable bearing surface left. Then a rather thin open head makes it easier to see all blighted shoots or spurs before the injury has spread very far; and all spurs can be removed from the lower part of the main branches, thus reducing the danger of getting infection into that part.

If the open head form is used it does not seem to be as important with the pear as with the apple that the uppermost branch be the largest. For, except following winter injury to the wood and excepting a few varieties such as Clapp Favorite, there does not seem to be the strong tendency for the branches to split down from the trunk with the pear that there is with the apple, though apparently the branches are more liable to break above the crotch. Then pear trees are generally planted more closely and earlier reach a condition when renewal pruning is desirable; and so the branches generally do not become so long. It seems probable, therefore, that except with a few varieties, such as Clapp Favorite and possibly Seckel, it is better to avoid the dwarfing effect caused by the pruning necessary to cause the uppermost branch always to be the largest. In sections where pear blight is serious, and in some seasons uncontrollable, it is particularly important that the young trees be pruned as little as possible in order that they may become large enough to bear a profitable crop as soon as possible. For, it is evident that the sooner the orchard comes into bearing the greater will be the chance that several profitable crops may be obtained before a serious blight year is encountered; and the less will be the investment in the orchard by the time it comes into bearing.

The tendency to drop the blossoms without setting fruit is very strong; and, with some varieties of pears such as Anjou and even Bartlett, if the soil nitrogen supply is adequate, renewal pruning in the dormant season seems to be the most effective means of causing a fair percentage of the flowers to set fruit. Cutting-back or thinning-back is, therefore, a more universally desirable practice with bearing pear trees than with bearing apple trees; generally being desirable with some varieties as, for example, Kieffer and Clapp Favorite, and possibly Winter Nelis, as early as the ninth or tenth year; slightly later with Bartlett and Anjou, because of their being later in coming into bearing; perhaps a little later with Bosc; and considerably later with varieties such as Seckel, Sheldon, and Superfin.

In training the young tree, what was said about the apple as to pruning at planting time generally applies with pears. For effectiveness in controlling blight it may be more important with many varieties of pears than with apples that the number of branches starting from the trunk be not more than four or five. Where the summers are warm and favorable for their growth, pear trees are more inclined than apple trees to make long straggling growth that may be seriously bent by a strong wind. Some cutting-back of these long twigs of young trees is more likely to be necessary with the pear than with the apple. With varieties such as Bartlett, the young trees of which make strong shoots that, in the next year, branch very little except near the top, the dwarfing effect of cutting-back such long twigs 25 to perhaps 40 per cent may be considerably less than it would be with trees not having this growth habit. And Reed (884) seemed to find only a slight dwarfing effect to result from a considerable amount of cutting-back of the long twigs of young Bartlett pear trees in the climate of Southern California.

It is the custom of some growers in the eastern States, particularly with the Kieffer variety, to cut the trees back very severely while young, cutting in such a way that they are flat across the top as in the accompanying illustration. The purpose is to increase the strength of the branches. From what we have learned as to the dwarfing effect of pruning, it is evident that such a treatment must greatly reduce both growth and early fruitfulness. In New York, Kieffer trees pruned that severely have generally yielded little or nothing by the time they were as old as the Kieffer trees whose yields were recorded in Table 55. In order to give the tree a chance to grow, it would seem better to do less pruning, and if necessary to remove the fruit from the ends of the branches each year until they are strong enough to withstand their load. This would give more fruit while the tree was young and more wood to bear fruit later; and if not enough fruit was left on the branches to break them, but only enough to bend them outward appreciably, that spreading might give a more desirable form of head.

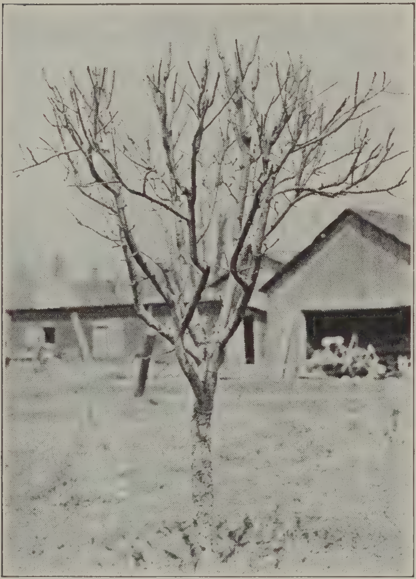

FIGURE 33. Severe pruning of young Kieffer pear tree.

We have seen, in Chapter 17, that bending of upright branches is a promising means of causing earlier fruiting of upright growing pear trees, though the practice must have much more study, or there must be more orchard experience with it before a dependable judgment can be formed as to how generally applicable under different conditions it may be. Experience in California, however, suggests that it would be a much better method for Keiffer in the east, than such severe cutting-back. Bending the branches early in the spring seems to cause them to develop a greater strength and to withstand any load placed upon them later by the fruit.

Perhaps more than with other fruits, pear trees have been grown on dwarfing stocks (the quince) both as bush trees and for training on walls or trellises. Du Breuil suggests that it will withstand the heat against a wall better than will the apple tree. The fruit's being of exceptional quality also has probably encouraged its being used in this way. It is more nearly worth the trouble involved in such training. Even in America, in the gardens of wealthy people, one sometimes finds pear trees trained to such forms. Modern practical use of such training seems to be in the system of overhead trellises as practiced in Japan. The trees there are trained low, perhaps because the fruits are bagged to protect them from insects and diseases, though it is possible that in hot climates, or climates where there is little winter chilling to end the rest period, more pruning is desirable. Such systems, of course, would be far too laborious for American orchard practice, even with fancy pears. Since nothing could be added to the works of Du Breuil (808), Hardy (824) and other older writers, readers are referred to them and to Waugh (915a).

The quince. Perhaps we have less evidence, either from experience of growers or from experimental study, concerning the pruning of the quince than concerning that of any other well-known fruit tree. It is generally the practice to permit the trees to form low, spreading heads, and to cut out some of the inner growth where the trees become too thick. The flowers are borne terminally on small shoots from lateral buds of twigs. If the quince responds in its fruiting in the way that most other kinds respond, better results may be expected if rather strong shoot growth is obtained each year. And so, it seems probable that as the tree grows older an increasing amount of annual renewal pruning may be beneficial. Tufts (907) suggests pruning enough to cause the new shoots to grow ten to twenty-four inches long. However, I know of no records of experience from which conclusions may be drawn.

The peach. We have seen that with the apple and the pear all the twigs might be pruned away and yet the tree might bear a very heavy crop from fruit buds left on the spurs. With the peach, however, all the fruit buds are borne laterally on twigs, including short, spurlike twigs. And if the twigs should be pruned away in the spring there would be no fruit borne in the following summer except that borne from fruit buds on twigs too short to be removed. If the twig is a rather short slender one, the buds are generally borne singly in the axil of a leaf, while if the twig is a strong one, there will often be at a node one large and two small leaves subtending two fruit buds with a wood bud in the center (sometimes all three are fruit buds). If the twigs are so small that buds are borne singly there are few wood buds, and the twigs tend to die after the fruit is borne. With the strong twigs, while many die after bearing a heavy crop, many send out new shoots. Further, while with the weak twigs the buds at the base surrounded by the bark of the trunk or branch from which the twig grows, tend to remain dormant, with strong twigs, even if they die back, many of these buds tend to grow, giving new strong shoots. Furnishing an abundant nitrogen supply increases the number of these buds to grow upon weak trees and even upon trees making rather strong shoot growth. If conditions are such that the shoot growth is rather weak and slender there is a tendency also for a smaller number of shoots to grow and for these to be only at the ends of the branches where growth is the strongest. It is because of this habit that in any peach-growing section it is soon found that the trees are strikingly benefited by renewal pruning.

At an earlier age than with most other fruits — usually by the time they are six or seven years old or even earlier — peach trees need such renewal pruning. Usually, if it is not given, not only will the tree become weak and straggling, but, in most climates, the fruit will tend to be small. This smallness of the fruit of unpruned trees will result partly from the fact that so many fruit buds are formed that cutting away of many of the buds in pruning is beneficial, and partly from the fact that the weakly growing tree is unable to supply water and nitrogen enough to cause the development of large fruit. Such renewal pruning seems, almost certainly, to prolong the life of peach trees. In New York, peach orchards receiving annual renewal pruning seem to continue profitable at least eight or ten years longer than do orchards not so pruned.

Climatic, as well as soil conditions, influence the amount of response which trees will make to such pruning and the degree of injury which will follow lack of such pruning. Thus, in New York along the Great Lakes, peach trees twelve to fifteen years old that have had very little cutting back will be tall and straggling, but more vigorous than trees of such ages in apparently as good soils in Missouri, or other sections where summer transpiration is probably larger than in the Great Lakes region. The fruit on such trees near the Great Lakes may be nearly as large as that on trees having renewal pruning, while in Missouri and in some of the peach-growing districts of California, much renewal pruning seems necessary, if fruit of large size is to be obtained. In the Great Lakes region peaches of the varieties generally grown, ripen about September 10, or later. During several weeks preceding, the weather has generally been cooler, the air more humid, and transpiration probably lower than earlier when fruits would be ripening if grown in lower latitudes. However, while in a section like that around the Great Lakes neglect of renewal pruning is less disastrous than elsewhere, such pruning is desirable to prolong the life of the tree, to keep it at a manageable height and to insure the development of an adequate amount of fruiting wood.

While renewal pruning may improve the vigor of weak trees, it can do so only at the expense of size; and, if the nitrogen supply is inadequate, the trees will have to be kept far too small to give the maximum bearing surface to the acre. Unless there is an inadequate water supply in a considerable percentage of the years, the nitrogen supply should be maintained high enough that the trees need not be pruned so much that they are kept too small to occupy all the available space in the orchard.

In New York, cutting back to lateral branches, thinning back, as discussed in Chapter 17, seems to have given better renewal than has shearing back to masses of stubs, the fruit being of as good size, of better color, and of better form. With the shearing some is distorted against the stubs. In California, thinning-back, "long pruning," has seemed to result in the production of smaller peaches than were produced by trees whose twigs were sheared back each year to rather short stubs. It may be that this reduction in size of fruit was due only to the fact that more fruit was left on the tree, or that a larger amount of foliage was left to reduce the water supply of the soil; and that all that would be necessary in order that the fruit on long pruned trees might be as large as that on sheared trees would be either to thin the fruit enough to leave no more on the long pruned trees than would be left by shearing, or to prune severely enough by the long pruning method to reduce the leaf surface to what it would be on sheared trees. On the other hand, it may be that fruits, though well spaced on a few long twigs, will not be as large as if the same number of fruits were on more twig stubs. The conduction of water may possibly be less efficient through a single bent fruiting branch than through several smaller branch parts to the same number of fruits and perhaps about the same leaf surface. Further, the crowding of the bloom and of the young fruit on a long branch before thinning time might reduce the possible size of the fruit in spite of thinning.

Tufts (907) says, however, that with some varieties, particularly Tuscan and Phillips Cling, the fruit buds tend to be mainly toward the ends of the twigs and that with such varieties whole twigs must be left. Healthy but rather short twigs starting from close to main or strong secondary branches are left, much the larger percentage of the twigs being cut out, and, in so far as possible, branches that fruited in the previous year being cut out or cut back to twigs near their bases. In some sections of California fair results seem to be obtained by what is called pole pruning. The tree is trained to a considerable number of branches. From each of these each year, all the wood that has fruited is removed, leaving only twigs starting directly from the main branches or from very short stubs on the main branches. With this system the improved size seems to be due to the severity of the pruning. Figure 34 is of a tree pruned in that way. In good soil more branches are generally left; but each branch is pruned in the way shown. Naturally it requires much pruning while the tree is young to shape to such a form; and as to whether or not the form is enough more valuable for mature trees to justify the delay in fruiting necessary to obtain it, the results of no careful study have come to my attention.

Peach trees one year from the bud (two years from the seed) are generally planted; though in sections where the growing seasons are long "June buds" are used, the seedlings being budded early in summer, the seedling tops being removed and the inserted buds starting growth rather soon. Such trees, dug a year after the seeds are planted, tend to be small.

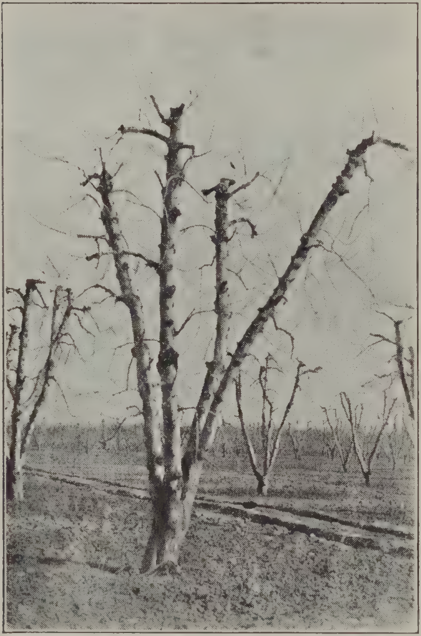
FIGURE 34. Pole pruning in a California orchard. The fruit will be borne on the twigs left on stubs along the main branches. Where the soil is rich and the water supply good, more branches may be left. (After Tufts.)

At planting the trees are cut back to stubs generally fifteen to thirty inches high, but small trees are often cut back to six inches in height and large ones are sometimes left thirty-six inches high or higher. Sometimes, with large trees, instead of cutting the branches close to the trunk, stubs about an inch long are left where it is desired to have permanent branches start. I do not know whether or not this increases the probability that branches will start from the buds at the bases of such stubs; these buds would be left if the branches were cut close to the trunk. Blake (767) found that if the peach tree is left entirely unpruned when planted, the total length of branch growth made in the first summer will be less and the branches more slender, the greatest reduction being on trees that were largest when planted. Small trees (three eighths inch in diameter) made the best growth when cut back to six-inch stubs when planted. Cutting back rather large trees (three fourths inch in diameter or larger) to that extent reduced the amount of growth made. Some growers cut the trees back to stubs eight to ten inches high to force the branches to start very low. As Blake has suggested, it does not follow that the bearing surface of such a tree will be lower than if the branches started twelve to twenty-four inches above the ground. It probably makes very little difference whether the lowest branches start six inches above the ground or twelve to twenty-four inches, except that the greater height will be the more convenient for working around the trees.

Usually three or four branches well distributed around the trunk are all that should be left with a young peach tree. If pole pruning is practiced these are caused to fork by pruning them back to short stubs in the second spring. Since lower branches grow as rapidly as branches starting higher on the trunk and since the peach tree so early reaches the maximum possible size for the planting distance generally used, any branches starting other than these three or four permanent ones contribute rather little toward the growth of the tree and can bear little before they begin to interfere with the growth of the permanent branches. It seems best, therefore, in starting a young tree to remove at once all except the three or four permanent branches, particularly if it is desired to have the lowest branch fifteen to twenty inches above ground.

It seems probable that under some conditions as soon as growth starts during the first season in the orchard it might be desirable to remove all shoots except the three or four that are to form the main branches. An experiment in the Cornell University orchard (782) furnished some information concerning this practice. Medium grade, northern grown peach trees were planted about four feet apart each way in a gravelly soil. They were pruned back to stubs about two feet high. With forty-nine of the trees all opening buds except about five, distributed around the top, were removed in the spring after planting. These trees were not pruned in the second spring. With forty-seven other trees, well distributed in the same planting, none of the starting shoots were removed in the first summer; but all branches except about five well distributed around the top of the trunk were removed in the spring before the second summer. At the end of the first summer the leaf surface of the average one of the former trees was 2259 square inches and that of the average one of the latter 2655 square inches. The size of the top seems to have been slightly reduced by the removal of starting shoots. In the second spring, however, the average branch that could be left near the top of the trunk of the non-disbudded trees was smaller than with the disbudded ones, and the leaf surface throughout the second summer was smaller. The trees were cut off at the surface of the ground and weighed at the end of the second season. The average weight of the trees disbudded early in the first season was 4.2 pounds, while that of the trees not disbudded but with the excess branches removed in the spring of the second season, was 3.7 pounds. The removal of the excess buds when they started in the first season clearly gave best results. However, the difference was due to the fact that branches starting near the tops of the trunks were selected. For, with the non-disbudded trees, the average branch before pruning at the beginning of the second season was 20.2 inches; yet, the average length of the branches left was only 18.1 inches, the branches low on the trunk being larger than those around the top. If the four largest branches had been left with each class, the average branch of the disbudded trees would have been 29.3 inches long and .43 inch in diameter at the base, while that of the non-disbudded trees would have been 28.7 inches long, and .43 inch in diameter at the base. In other words, the heads at the beginning of the second season would have been of about the same size, with the root systems of the non-disbudded trees probably slightly the larger due to the larger leaf surface in the first summer. However, with these latter trees the four largest branches could not all have been left in every case; for sometimes two of the largest branches would have been on the same side of the trunk. Yet it is reasonably certain that if with these latter trees the largest branches well distributed around the trunk had been left without reference to the distance from the ground, the heads would have been approximately as large at the end of the second summer as the heads of the disbudded trees. It seems probable that if the grower is anxious to have the branches of his trees start high enough from the ground for him to work around them conveniently, he will have a larger tree by the third summer if he will shape it during the first season in the orchard; that is, if, soon after growth starts, he will rub off all new shoots except those which he wishes to form the permanent branches. If he does not care how near the ground the branches start, little or nothing will be gained by such a practice.

Peach growers generally cut back the branches of young trees rather severely, the purpose being to force a stocky growth. Under some soil or climatic conditions, the shoots grow very long with little branching during the first summer, and in the second few, if any, secondary branches form near the bases of these. With such trees a considerable amount of cutting-back is necessary in order to force the formation of secondary branches lower on the main branches. However, generally in good soil, the secondary branches are low enough. Blake (769) found that while a slight amount of cutting-back in the second and third springs did not appreciably reduce the crop in the third summer, cutting back the branches one third to one half their length reduced the yield in the third summer about sixty-five per cent. In an experiment at Hilton, New York (782), such cutting in the second, third, and fourth springs reduced the yield in the fourth summer from 28.0 pounds to the tree to 11.8 pounds to the tree. During these first few years, apparently, cutting-back should be done only in specific cases where it is necessary to force desirable branching. Since the peach tree tends to be rather short-lived, it is more important than with most other kinds that it reach profitable bearing as soon as possible. However, the tree early begins to make weak annual growth unless it has some renewal pruning; and after it has borne one or two heavy crops it will generally need some cutting-back, the amount increasing annually until it is as large as it can conveniently be with the planting distance used, when it should be pruned about enough each year to prevent its increasing permanently in spread of top.

In some years when so many fruit buds have been killed in winter that not enough are left for a full crop it may be best to prune very lightly in order to leave as many fruit buds as possible. Pruning more severe than normal can then be given in succeeding years.

When, for any reason, trees have become tall and unmanageable and perhaps the growth has become too weak, some growers take advantage of a year when the buds have all been killed to cut back rather severely, "dehorn." Sometimes the main branches are cut back to stubs three or four feet long. The bearing surface may be thus so reduced that the amount of fruit borne may be much less than it should be in the second and even in the third year after such pruning. However, if the branches are left six or seven feet long with stubs of the secondary branches attached, the crop in the second year after the pruning may not be reduced; in fact, it may be actually increased as a result of the pruning. Pruning even no more severe than this last should not be done in a spring following a winter that has severely injured the wood. For, while under some conditions severe pruning seems to increase the ability of the tree to recover from such injury, under most conditions, it certainly very greatly increases the probability that the tree will die. Only moderate pruning should be given such injured trees.

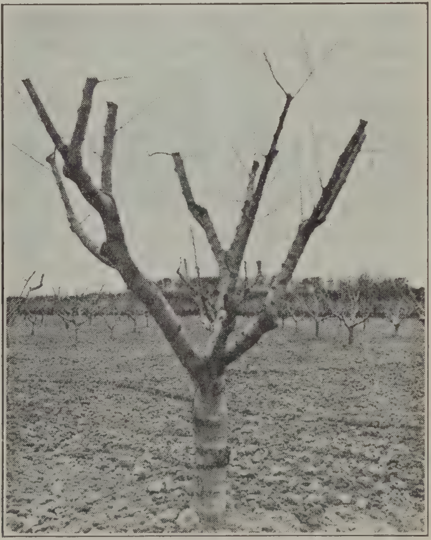

FIGURE 35. It is doubtful if such severe pruning as this is ever desirable.

The apricot. Apricot trees are usually pruned at planting much as are peach trees, though, if there are branches, stubs of these may be left four to six inches long at positions where permanent branches are wanted. The apricot is grown commercially in the United States only on the Pacific Coast; and methods of pruning based on experience can, of course, have developed only in that section.

A much larger percentage of apricot fruits than of peach fruits are borne on short branches or spurs. According to Tufts (907) these generally live only about three years, the fruit, of course, being borne only on the part that grew in the previous season. Many of the spurs that replace the old ones grow directly out of the large branches. Whether these grow always from dormant buds or sometimes from adventitious buds, I do not know. The twigs of the apricot tend to be longer than those of the peach. In some of the valleys of California, the longest twigs do not bear fruit buds except on the terminal six to eight inches, the last cycle of growth. Shorter twigs, about two feet or less in length, may bear fruit buds throughout their length. Trees three or four years old may bear heavy crops, the fruit being thickly distributed on short twigs and spurs and even along some of the twigs of considerable length. Since pruning causes the growth of very long shoots that tend to bear fruit buds only at the end and since the cutting-back of these shoots greatly reduces the number of spurs, the response of young apricot trees to light cutting-back may resemble the response of young apple and pear trees, in that pruning reduces the fruit-bearing surface more than it reduces growth. And, since fruiting of the young tree may be so heavy, moderately severe pruning may not delay the tree in becoming large enough to bear profitable crops. Wickson (918) says, "Thousands of trees have been ruined by literally breaking to pieces with the weight of their fruit, and being torn by winds of only ordinary velocity."

It has been the custom in California, usually, to start the apricot tree with about three branches, to cut to rather short stubs after the first summer's growth, and in each succeeding year to cut all the twigs to rather short stub, the purpose being to develop strong branches with many strong secondary branches. After the trees were of mature bearing age all the twigs were cut back even more severely each year, nearly all the fruit being borne on the short twigs and spurs along the branches. In some sections, as, for example, the foothill sections near Riverside, California, the severe pruning of the mature trees served to cause the continuous renewal of the spurs along the old branches as well as along the younger ones and the fruit under the stimulus of such pruning was of larger size. The spurs were in partial but not injurious shade, and the fruits were of better quality for canning because of their being protected most of the time from direct sunlight. In richer land with a larger water supply, conditions found at Winters and at Davis in northern California, the growth following such severe cutting-back was too thick and sometimes injured the spurs and caused the fruit to ripen unevenly.

The severe pruning of the young trees greatly reduced the crop during the first six years or more in the orchard. Thus, Tufts (907) found the average yield of sixteen Royal apricot trees six years old to be 23.9 pounds, while the average yield of as many trees with the branches thinned out and some of the end ones cut back to laterals was 200.6 pounds. However, the former averaged 8.3 and the latter 13.4 fruits to the pound.

With mature trees, also, Tufts (904) found that by thinning out some of the twigs and branches and leaving some unpruned he could greatly increase the yield, under conditions prevailing at Winters in northern California. However, he called attention to the fact that the fruit was smaller. In an experiment at Davis with trees eight years old, that had been cut back severely, varying the amount of pruning gave the results shown in Table 58, there being five trees to the plat (Tufts, 907).

TABLE 58. AVERAGE YIELD OF TILTON APRICOT IN POUNDS TO THE TREE

PRUNING TREATMENT	1916	1917	1918	1919	1920	1922	AVERAGE
Thinned and headed severely	19	59	29	73	24	52	43
Thinned and headed lightly	20	119	97	169	252	241	150
Thinned out only	60	171	178	137	172	214	155

The lightest pruning caused the greatest yield during the first three years; but the excessive fruiting seems to have weakened the trees; and in later years the better yields were on the trees having some cutting-back of twigs.

For a number of years there was practiced by a considerable number of growers in California what was known as long pruning. With both the old and the young trees the branches were thinned out and thinned back; that is, the only cutting-back was the cutting of branches back to laterals. This represented a pruning much more severe than is practiced with any fruit in the East unless it be with the Kieffer pear or the Burbank plum; but it was not nearly so severe as the growers of California had been practicing. However, the practice did not prove satisfactory with apricots. The fruit was too small for profitable canning, drying or marketing fresh. And much thinning did not greatly improve it. It seems that the excessive blooming and the setting of excessive numbers of fruit had, before thinning time, reduced the possible size of the fruit. The fruit on the ends of the long slender branches was particularly small, and the exposure to direct sunlight seemed to cause it to crack worse than did fruit in partial shade.

The pruning that the growers gave young apricot trees before long pruning was adapted tended generally to cause the development of a good system of branches on which spurs could grow. However, it seems that by leaving the branch stubs longer each year, but not enough longer to cause a slender straggling growth, the tree could be brought to profitable bearing earlier. With the mature bearing trees in California, it seems probable that most of the long twigs must be cut back and the fruiting must be mainly on spurs and short twigs. In rich soil excessive shading can probably be avoided by letting the tree grow taller and spread a little wider than was the practice of some of the growers. This would give a larger leaf surface on twigs and spurs and would check the excessive shoot growth. Tufts (907) recommends that the cutting-back of mature bearing trees be severe enough to cause the new shoot growth to be ten to twenty-four inches long. This would require that the trees be kept considerably smaller in some soils than in others.

The almond. The almond also is grown commercially in America only on the Pacific Coast. Wickson (918) says: "The pruning of the almond is very simple. The tree should be headed low and pruned during the first three years . . . to secure a shapely, strong tree. After the third year little pruning is required except to thin out objectionable branches by winter pruning. There is danger of allowing the trees to become too dense. Shortening in, as practiced with the peach, is not desirable with the almond." Taylor (902) recommends pruning at planting something like that for the peach, with much less cutting back of the young trees than is ordinarily practiced with peach trees during the first few years of growth. The recommendation of Taylor is in line with our present knowledge that cutting back young trees reduces their growth and delays their fruiting; and, except in special cases with unusual development of the branches, it does not tend to give better form to the tree. Generally the established tree is pruned very little. Some thinning out of the upper branches may be practiced, the purpose being to let in the light and thus to keep alive more of the spurs and twigs borne in the tree. Trees so handled, particularly if the water supply is limited, may reach such a weakened condition that most of the bloom falls without setting fruit; and there may be little bloom. Renewal pruning given every year or perhaps every two or three years after the trees have reached maximum production, should greatly delay their becoming too weak to fruit well. Tufts (907) suggests cutting back to laterals far enough down the branch for it to be a half inch to an inch and a half in diameter. Not many cuts would thus be made on a tree in one year; and such pruning could not be very expensive.

Sometimes, after the trees have become very weak and have begun to drop nearly all their blossoms each year without setting fruit, the branches are cut back to stubs only two or three feet long. Many vigorous new shoots grow from these, and within two or three years the new branches thus formed may set fruit; though almost none may be set on adjacent unpruned trees. Such experiences, in so far as I am aware, are to be observed only in orchards where the rainfall is inadequate, and irrigation is not practiced. It is probable that such pruning, by so greatly reducing the leaf surface, conserves soil moisture and, by increasing the water supply to the fruit, prevents abscission. After such pruning it is necessary to thin out some of the shoots; and the tree will for several years be too small to bear as large a crop as the soil moisture supply is capable of supporting. While I know of no experience, it seems to me that leaving the branch stubs longer with some stubs of secondary branches attached in the way that was recommended for peach trees might give better results, since there would be room for growth of more shoots; and a profitable crop might be obtained in the second summer after the pruning. In fact, it is probable that, if the trees have not become exceptionally weak, severe thinning back of branches in very early spring, leaving some fruiting branches, might cause the holding of a crop in the season following the pruning. And it would probably cause the growth of strong shoots farther down in the tree so that, in succeeding years, the branches could be still farther shortened

The plum. Although there are a number of species of plums, the pruning requirements may be discussed together. Under most climatic and soil conditions, the trees of nearly all varieties are a little older than are peach trees before they are large enough to occupy all the available space at the planting distances used, and before they begin to bear heavy crops; and probably with most varieties, pruning the young trees severely causes a greater reduction in the amount of fruit borne by the time the trees are ten years old than does such pruning with the peach tree. In the experiments at Cornell University (Table 55), the pruning necessary to give the trees the modified open head form caused a greater percentage reduction in the amount of fruit borne by the time the trees were nine years old with the Shropshire Damson than with the other varieties studied. The trees of this variety grow more slowly than do those of the other varieties studied; and while they are young there is less shading out of the lower branches. The fruit sets rather well; and, more than with trees that grow rapidly, the rate of increase in size tends to be the dominant influence as to yield. With such slowly growing and rather early fruiting varieties, the pruning of young trees should, therefore, be the minimum that will prevent the development of undesirable forms. With some varieties of European plums, trunks of old trees may rot down the center if all the branches start from the same height on the trunk, and are of approximately the same size. Such rotting is even more liable to result if a branch in the center is so crowded by other branches that it cannot grow well and cannot be cut out close enough to the other branches for the wound to be covered before the organisms get well started into the trunk. With the Agen prune tree in some sections of California, where a three-branch system is generally used, there is often a cup-like depression formed at the union of these branches with the trunk; and the tendency is so great for the tissue in such a crotch to die and permit rotting down the center of the trunk that some advocate having only two branches to form the head. With two branches the water would always drain out of the crotch; and no tissue would be surrounded and compressed in such a way that it would become very weak or die. Training to a central leader or to a modified open head, the uppermost branch being considerably the largest and the others so disposed on the trunk that none would crowd at the base, would have the same effect.

Unpruned trees of most varieties of plums tend to continue in a reasonably healthy condition to a considerably greater age than do unpruned trees of the peach. With most varieties, however, after the trees are of mature size, renewal pruning seems desirable for its causing the growth of healthy fruiting wood; for the purpose of keeping the tree from growing too high; for convenience in picking and in other work; and especially for the effect on the size of the fruit.

Trees of Japanese plums generally decline in vigor enough to make renewal pruning desirable earlier than do trees of most other varieties. In some sections, killing of the fruit buds in late winter is rather common. If the trees receive pruning and other care such that the annual growth is rather vigorous, fruit-bud differentiation is delayed and the flower parts, not being in as advanced a stage of development when the frost comes, will be more resistant. With the Burbank variety, there is a very general practice to cut the twigs back to very short stubs; and Waugh (915) says the practice was common as early as 1901. Such pruning reduces the tendency of the branches to droop and tends greatly to increase the size of the fruit. At the Cornell experiment station the size of the fruit was not appreciably increased by rather severe pruning of trees no more than nine years of age. However, the fruit was thinned on both the pruned and the unpruned trees; and in pruning the stubs were left eight to ten inches long. It is probable that, if the fruit had not been thinned, that on the severely pruned trees would have been considerably the larger. And it is certain that, if in pruning the stubs had been left only two or three inches long, there would have been a greater increase in the size of the fruit.

Large fruit is preferred in the fresh fruit market; and, with all varieties grown for fresh fruit, renewal pruning may be desirable after the trees are old enough for the fruit to be rather small. In sections where brown rot causes loss, the pruning should, in so far as it is possible, be a thinning back (long pruning) in order not to cause the formation of a very dense head in which rotting will be more serious. In fact, such long pruning being the more cheaply done is probably best under most conditions. However, if the size of the fruit is to be maintained, long twigs that would bear great masses of fruit must generally be cut back to stubs.

Generally, considerably less pruning is given if the variety is grown for drying than if grown for fresh fruits. Some thinning-out in the top is necessary in order to prevent the fruiting wood from dying in the center of the tree. With fruit for drying, one may be interested in the total yield rather than in the size; and, since the fruit is not picked, but is permitted to fall to the ground, there is no great advantage in pruning to keep the tree low. Wickson (918) says that by the year 1900 growers had learned that it is not wise to cut back bearing Agen (French) prune trees. He suggests, however, that not all varieties used for the dried fruit are well adapted to the system of little pruning. Lewis (849a) says that the growers will obtain better results by suppressing the terminal growth as well as thinning out the center. Severe heading back and leaving the growth very thick would tend to give less desirable fruit for drying, but renewal by thinning back would not have such an effect, would be less expensive, might prolong the life of the tree, and might improve the quality of the fruit. Tufts (907) recommends thinning back for the prune cutting to a lateral at which the part removed is one fourth of an inch in diameter or less.

The cherry. Sour cherries (*Prunus cerasus*) are most largely grown in the northeastern part of the United States, particularly in the Great Lakes region. It is almost the universal practice to prune this tree very little. The pruning even at planting time, for some sections at least, should be different from that practiced with other fruits. Hedrick (164) says that at the New York Experiment Station it has been found that a tree two years old is less liable to die following transplanting if, instead of cutting back twigs, they are merely thinned out to the necessary four or five. This is certainly true in the hotter sections south and west of New York. In Missouri, one can be almost certain that one will kill a cherry tree by cutting back the twigs. On the other hand, Roberts (890) recommends severe cutting-back at planting for the climate of Wisconsin; and in the more humid northern sections, such cutting-back is generally practiced. In some years there may be a dying of the twigs; but, if there is, that result is not as common as it would be in Missouri. And in New York I have occasionally observed better results to follow cutting back the twigs at transplanting than leaving them unpruned. Sometimes when the twigs of the newly transplanted tree are left unpruned, the new growth is very weak, the leaves fall early, the wood is not well ripened, and the tree is killed in the following winter. Until we know why, in some sections at least, twigs pruned in the spring when the tree is planted often die, the better practice would seem to be to cut away all twigs except those wanted for permanent branches and to leave those unpruned. However, the problem should be studied as to the response both in sections where the summers are long and hot and transpiration is high and in sections where the summers are shorter and cooler and transpiration is lower. It may be that in a section of the former type, such as Missouri, fruit buds tend to form toward the base of the twig in the axils of all but very weak leaves, and that, if a twig is cut back, there is left no normal bud from which there may be shoot growth.

It has generally been assumed that the cherry tree will fruit better with little pruning and that as it grows old it does not show the need for renewal pruning that other fruit trees show. But Roberts recommends more pruning for the cherry in Wisconsin and training to an open head. His recommendation is based largely upon the fact that spur buds are more resistant to winter freezing than twig buds; and serious losses are encountered in that state from winter freezing of the buds. He seemed to find that spur buds are rather quickly shaded out on trees with round compact heads, and that there are more spur buds on open head trees.

In maintaining a large spur system, the length of new shoot growth made each year is of much greater importance than is the form of head. If the twigs are short, all except the terminal buds may be fruit buds and no spurs will be formed; but if vegetation is stronger and the twigs are rather long, some of the buds will not be fruit buds and will form spurs. Since many of the spurs live and fruit during a number of years, developing a spur system tends to increase the bearing surface of the tree.

On account of the tendency for all the lateral buds on short twigs to be fruit buds, the bearing surface of fairly young trees may not increase if they cease to make rather long shoot growth. Roberts counted the buds on trees of different ages, obtaining the results shown in Table 59.

TABLE 59. SHOWING THE NUMBER OF FRUIT BUDS ON CHERRY TREES AT DIFFERENT AGES

Age of Tree	No. of Fruit Buds on Twigs	No. of Fruit Buds on Spurs	Total No. of Fruit Buds to the Tree	Percentage of Buds on Spurs	Nature of Tree
4	80	1727	1807	95.5	Large growth
5	1632	1292	2924	44.2	Average tree
6	3471	6630	10101	65.6	Very low open tree
6	4019	4899	8918	54.9	Large, open top
6	3571	3666	7237	50.7	Medium size, open
8	5363	11120	16483	67.5	Large, very open
9	4820	9626	14446	66.6	Very open tree
9	8481	7682	16163	47.6	Spreading, dense
10	8652	5617	14269	39.4	Large tree, dense
10	5458	11120	16578	67.1	Large tree, open top
12	6520	11837	18357	64.7	Very open top
12	16450	6451	22901	28.2	One year after dehorning
14	9936	5811	15747	36.9	Topped tree, low wood dead
14	7956	9240	17196	53.7	Nitrogen plat, large growth, dense
14	9493	7229	16722	43.3	Phosphate plat, little growth dense
16	4867	7854	12721	61.9	Low wood dead, little growth,
18	9603	7427	17030	43.6	Strong growing, old tree
20	4464	9792	14256	68.9	Average tree, low wood dead
22	8315	8165	16480	49.6	Large tree
22	10496	9864	20360	48.5	Very large tree
24	3108	5846	8954	65.1	Medium size, very little growth

It is interesting to note that one year after severe pruning a tree has above the normal number of fruit buds. Of course, more trees should be included before one could be certain, but it seems that the maximum number of buds to the tree is reached at eight to twelve years of age. From these results it seems probable that rather severe renewal pruning would not reduce the fruiting even temporarily and would increase it in succeeding years. In fact, Roberts (1124) seemed to find that rather severe pruning may be given trees eight years old without even reducing the crop in the year of the pruning; the pruning apparently causing a larger percentage of the flowers to set fruit. With soil and climatic conditions more favorable for the setting of fruit, severe cutting-back of mature trees previously unpruned might reduce the crop in the season of the first pruning and would increase it in succeeding years by increasing the number of spur fruit buds to form. Roberts found that in 1920 and 1921, the crop was much larger on the trees pruned heavily in 1919 and more lightly in 1920 and 1921 than on unpruned trees or trees pruned lightly in each of the three years. In pruning, Roberts cut back to secondary branches; and it seems probable that with the sour cherry such thinning-back should be the universal rule. It will not only increase spur formation, but will probably tend to keep the spurs alive longer by preventing the shade from becoming too dense in the tree.

The spur of the cherry is in reality a very short twig that bears fruit buds in the axils of the leaves and generally a wood bud terminally. The amount of growth from a spur and the number of fruit buds formed tend to be less in each succeeding year. And so, even with rather open trees of Early Richmond and Montmorency, the spurs gradually die off. The broad spreading types of trees such as English Morello have not been studied. It may be that the spurs tend to live longer than with upright trees such as those of Early Richmond. However, the twigs tend to bear mainly fruit buds unless they are caused to make very vigorous growth. While there is need for study with varieties other than Montmorency and Early Richmond, it seems probable that with nearly all sour cherry varieties, it is best to start the young tree with no more branches than can grow permanently without crowding at the base, and to prune very little until the tree is six or seven years old, when renewal pruning should begin, the amount of pruning increasing until the tree is as large as it can conveniently be with the planting distances used, the height permitted being no greater than that necessary to obtain the desired spread of the branches.

The sweet cherry (*Prunus avium*) is grown only to a slight extent in any part of the United States except the Pacific Coast. As grown in the northeastern section of the United States, according to Hedrick (164), it may have a little pruning during the first few years, in order to shape it; but after that the only pruning is to remove crossing or injured branches. Of course, the experience of growers with sweet cherries in that section is too limited to give conclusive evidence as to best pruning methods. According to Wickson (918), nine tenths of the sweet cherry growers in California prune their trees to open heads with three to five branches, taking about five years of somewhat severe pruning to give the desired form. During this time the cutting-back of branches is to outgrowing secondary branches, so as to give a spreading form. This seems desirable in order to avoid the very great height to which sweet cherry trees grow. Lewis (849a) says that there seems to be a prejudice against pruning the sweet cherry tree. He recommends, however, that it be pruned during the first six years about as the apple is pruned to obtain the open head tree of the Pacific Northwest. He thinks that summer pruning gives better results than dormant pruning, particularly for the purpose of overcoming the thin, leggy type of growth that is common to the sweet cherry. Aside from the removal of all branches, except such as can be left permanently without crowding and injury at the base, the only pruning seems to be made necessary by the tendency of the young sweet cherry tree to grow very long shoots that in the succeeding year branch only near the apex, and, with most varieties, by the upright growing habit. It seems necessary, following the first and the second growing season and sometimes following each of several other growing seasons, to cut back such long twigs to a length of perhaps two feet in order that a good low branching system may be obtained; and some cutting-back to outgrowing side branches may be necessary with some varieties; though in my experience, the head of the trees is not very effectively spread in that way. It would be interesting to try the effect of spreading the branches forcibly by means of wires fastened to screw eyes in the trunk and the main branches. With some varieties, this might not only spread the branches, but by changing polarity, might cause the growth of basal buds without the necessity of heading back long twigs. However, in so far as bending has been tried it does not seem to have such an effect on the growth of dormant buds into secondary branches; and with some varieties at least, it seems probable that cutting-back will be necessary for that purpose.

In Pacific as well as Atlantic Coast sections of the United States, mature sweet cherry trees are pruned very little. However, the growth tends eventually to become very weak, in many cases in the Pacific Coast region weaker in the top than lower on the branches. It seems probable that some renewal pruning, always cutting back to a secondary branch, might be desirable after the trees have reached the stage of weak growth in the top; though, until the problem has been studied or the practice has been tried by growers, it is not safe to express an opinion as to how effective renewal pruning might be.

Citrus fruit trees. It is not the purpose here to discuss the minute problems of pruning citrus fruit trees, as I have not had the experience with them that would enable me to discuss problems that have not had experimental attention; and with all fruits by far the larger number of problems come in that class. It seems worth while, however, to examine what experimental evidence has been published, to see if trees of these species, which differ so greatly in their growth habits from deciduous trees, are like them in their response to pruning.

Since citrus trees are grown in sections where the growing season is very long, it would seem that they might require fewer years in which to grow a new fruiting top after severe pruning than would trees in sections where, during much of the year, the temperature is too low for growth. And bearing trees cut back severely for top working seem to grow a new top capable of bearing a large crop much more quickly than would be possible with apple trees pruned as severely. Shamel (895), reporting observations in orange orchards in Brazil, suggested that after the trees are twenty to twenty-five years old very severe pruning, even cutting to stumps, may cause Navel orange trees to bear heavier crops within a few years after the pruning. On the other hand, Hume (835) says, "As a whole, no group of fruit trees requires less pruning than citrus trees after they are once set and established in the grove. Most of the pruning is in many cases given at the time of planting and with the exception of the lemon systematic pruning such as is given peaches is not practiced." Wickson (918) also suggests that experienced growers of California think the orange should be pruned as little as possible. Coit (795) seems to believe in a rather large amount of pruning to shape the tree. In fact, practically all of the pruning recommended for the orange seems to be for the purpose of shaping and not for renewing or invigorating, such as bearing peach trees and sometimes other deciduous fruit trees require. All three writers recommend a rather large amount of pruning for the lemon. This is generally recommended for shaping on account of its straggling habit of growth, and its tendency to bear its fruiting wood far out on the ends of these straggling branches. According to Powell (876), the lemon growers of Italy do very little pruning and yet he reports that their yields are much larger than those obtained by California growers.

What experimental evidence there is available indicates that pruning may easily be too extensive. Shamel (896) gives striking proof of this. In a grove of healthy Navel orange trees twelve years old in 1914 five different pruners of considerable experience pruned, each according to his view, every alternate tree in a row of twenty. Half of the trees in each row were left unpruned. The effect of the pruning done by each pruner was greatly to reduce the yield during the two succeeding years, the reduction during the first succeeding year amounting to from thirty-four to one hundred per cent; and the average crop for the four succeeding years was from six to twenty per cent less on the pruned trees than on the unpruned ones. Practically no pruning was done during the four years after that given the first year; and so the reduction in yield during the four years all resulted from one pruning. There was a slight increase in the percentage of first grade fruit on the pruned trees in the crop succeeding the pruning, but not enough materially to reduce the financial loss from the pruning. These results indicate that the amount of pruning given young healthy Navel orange trees should be small. It also suggests that growers had not learned the best style of pruning or training for orange trees. Reed (880) and Surr (901) report experiments with moderate and heavy pruning of Navel orange trees twenty-four years old, that had been declining in yield and seemed to need renewal. The trees were tall and rather dense and it was thought that they might be benefited by rather severe pruning. There were 586 lightly pruned trees, and 290 pruned severely in 1915 and lightly afterward. The first year (1916) succeeding the pruning the yield was 146 pounds to the tree lightly pruned and but seventy-six pounds to the tree heavily pruned; and the average for four years was markedly larger for the lightly pruned trees. Surr suggests that, since the crop on the heavily pruned trees was about fifty per cent of that on the lightly pruned trees in 1916 and about ninety per cent of it in 1919, eventually the heavily pruned trees may be expected to surpass the lightly pruned ones. Such a conclusion may be suggested when the figures are examined without reference to the nature of pruning responses of fruit trees; but from what we know about pruning responses we would expect the difference in yield between the heavily pruned and the lightly pruned trees to be less in the second year after the pruning than in the first. In fact the reduction of the difference might be expected to continue into the third year.

The fruit was considerably larger in 1916 on the heavily pruned trees than on the lightly pruned ones, but no such effect was to be observed after that year. This increased size was probably due largely to the small crop; but, if it was due partly to the invigorating effect of the heavy pruning, then that invigorating effect was not evident by the second year after the pruning. There is always a large growth of new wood in the first season after severe pruning, due partly to the fact that a small crop is borne, but mainly to the fact that, at the beginning of the season, the root system supplying the reduced top is as large as that supplying the larger top of the unpruned tree. Before the end of the summer, the old balance between root and top will be reëstablished. If on the severely pruned tree, the wood formed in the year of the pruning was not all fruiting wood but would form fruit buds in the second season, then the gain in fruitfulness of the severely pruned trees should continue with the third season after the pruning. Most of the wood formed in the first summer after severe pruning seems to have been fruiting wood. For in 1917, the crop on the severely pruned trees was nearly ninety per cent of that of the lightly pruned trees. The percentage difference in the second season was only slightly greater than the difference in the fourth season. It seems probable that with large blocks of trees twenty-two feet apart, since with mature trees at that planting distance space in the orchard is the limiting factor as to growth, trees severely pruned in one year and lightly pruned in succeeding years would in a few years become as large as if they had been lightly pruned. However, the invigorating effect of a single pruning is only temporary; and it does not seem probable that, through any influence of the pruning, the severely pruned trees would eventually yield more than the lightly pruned ones, if that influence had not been shown by the fourth year after the pruning. It is probable, therefore, that the loss of fruit due to the single severe pruning was the reduced yield during the four years (13.78 tons for 269 trees), and probably a little more that would be experienced during one or more succeeding years; and it is probable that there will be no compensating increase later that can be ascribed to the one severe pruning.

Shamel (898) obtained results with Marsh grapefruit trees similar to those obtained with the orange. Four experts pruned plots of trees eleven years old, each expert leaving alternate trees unpruned. The trees had been injured somewhat by freezing. In all cases the average yield during a period of three years was reduced by the pruning, the more severe pruning resulting in the greater reduction. The amount of fruit going into the better grades was not increased by the pruning. Shamel (897) reports an experiment along the same plan with Eureka lemon trees ten years old and in good condition except that there had been some injury from freezing. One man pruned much more severely than the other. In both cases the pruned trees yielded in the succeeding years less than unpruned trees; but by the third year the trees pruned least severely were yielding as much as the unpruned trees. There were no more culls and but slightly, if any, more tree ripe fruits on the unpruned trees. What the relative yields would have been later we do not know, but the unpruned trees were becoming straggling and full of dead wood.

Culbertson (800) gives the results of some renewal pruning experiments with Lisbon lemon trees twenty-five years old. His pruning in the first experiment was a removal of branches that seemed undesirable. He says he removed by this method about sixty per cent of the foliage, though not more than thirty to forty per cent of the fruiting wood.

The crop was considerably reduced during the two succeeding years; but by the third or fourth year the yield of the pruned trees had come back to that of unpruned trees or slightly above. However, it was not large enough nearly to offset the greatly reduced yield during the first two years after pruning. The average size of the lemons from the pruned trees was six per cent larger than those from unpruned trees; and the percentage of the fruit that was ripe was a little smaller, but neither benefit was of enough importance greatly to modify the loss through the reduction in yield, which after two years and nine months was 59,732 pounds or about $1200 on 2.5 acres of rather severely pruned trees. Even with lemon trees then we can say that while they may regain their normal bearing capacity more quickly than do orange trees, yet there is with them a great temporary loss where the pruning is severe.

It seems that with the lemon, the grapefruit, and the orange any large amount of pruning of trees that have not reached a very low stage of vigor may be expected to cause a reduction in yield during several years without necessarily causing an increase later. It does not follow that a moderate amount of renewal pruning may not be desirable for mature trees. And it does not follow that trees may not become weak enough that rather severe pruning is desirable. In fact pruning severe enough to remove all young wood is thought by the best informed people to be desirable sometimes.

Hodgson (831), from observation in citrus orchards, recommends that young trees have three or four main branches distributed evenly about the trunk, so spaced that none will be pinched or crowded at the base by the growth of the others; and that very little pruning be given until the trees come into bearing, except the removal of crossing and interfering branches and suckers. And with upright, vigorous trees such as those of Valencia orange or trees that make a straggling growth as some lemon trees make, cutting back of long main branches may be desirable. There may also be many suckers to remove. He says that an unpruned young lemon tree will generally develop a rank growing, undesirable branching type and that for best results young lemon trees should be pruned lightly every three months during the first four growing seasons, only undesirable shoots and branches being removed; that during the first few years of bearing, perhaps from the fourth to the eighth or ninth years in the orchard, the pruning should be mainly the removal, while very small, of suckers from the trunk and branches and of vigorous "water sprout" like shoots from small branches, this being done twice during each growing season; and that during the next four or five years very little pruning will be necessary. Following this age a considerable amount of thinning-out of upper branches to let in light is necessary. As the tree grows older renewal pruning by cutting older secondary branches to main branches or the main branches back to secondary branches seems to become desirable. Lower branches that have ceased to bear should be removed. The bearing lemon tree tends to require more pruning than do other citrus trees and the grapefruit and tangerine somewhat less than most others. He says that, in California, old trees may become so weak and unfruitful that very severe pruning becomes necessary. He seemed, however, to find that much better results follow if, instead of "dehorning," cutting the branches all back to rather short stubs, the trees are "skeletonized" — that is, all the small branches cut off and the ends of all branches cut back — the trees thus having left all the main branches with the secondary branches and even stubs of the tertiary branches, but no twigs bearing foliage.

When citrus trees have been injured by frost, it has been found best to delay pruning until some months after growth starts. Growth is slow in starting from slightly injured parts; and, if one prunes too soon after the frost, one will cut away branch parts from which there would later be satisfactory growth. In other words, pruning soon after a freeze will generally be too severe pruning and the crop will be smaller during the succeeding few years.

Pruning trees of some miscellaneous species. It seems worth while to give brief attention to the special pruning requirements of a few other fruits, without in any case giving specific training details.

The olive, in some countries at least, receives a considerable amount of pruning to train the young tree and to maintain a supply of fruiting wood with the old tree. Kearney (841), describing the methods practiced in the region of Sfax in North Africa, says that the growers there avoid severe pruning of the young trees until they are three years old, because such pruning seems to interfere with the root growth. We have learned before that pruning by reducing the leaf surface reduces the root growth. However, in all cases, temporarily at least, it reduces the transpiring surface to a greater extent; and generally with other trees we seem to find that the drier the climate, the more it seems wise to prune at planting time, at least. Though with young trees in a soil in which no other crop is grown and weeds are kept down, there is generally little reason for pruning to conserve moisture. For even in rather dry climates until the trees are large enough to transpire rather large quantities of water, the supply is generally enough to support good growth. It may be that the reason for little pruning at this time in case of the olive in the section mentioned is to be found in their method of propagation. The trees are grown from truncheons of wood taken from the base of the trunk or from the large roots, the pieces being eight to ten inches long, averaging about four inches in thickness, and weighing two and one half pounds or more. These are planted directly in the orchard. Naturally the smaller the amount of pruning, the greater the leaf surface will be, and therefore the greater the root growth. And it seems probable that the sooner large roots are established in connection with the sprouts, the less danger there will be from injury to the tree by drying out or disintegration of this truncheon. According to Kearney, the practice of the growers is to let all the sprouts from the truncheon grow during the first year, removing all but two during the second year, and all but one during the third. Of course, because of the larger root system developed as a result of the growth of the additional sprouts, the growth of the sprout left will be more rapid. In that section when the trees are three years of age, the terminal shoot is removed, and the four next lower branches permitted to develop. The growers think that by this removal of the terminal, the tree begins to bear about two years earlier. The following year the tips of the four remaining branches are removed, and all the lateral twigs are shortened back except one. After this the pruning is such as to give the tree a well rounded and spreading form, with the branches well spaced.

Wickson (918) recommends a training for the young olive tree very much like that which is given other deciduous fruit trees in California, the vase form. Savastano (892) says that in Italy the pruning of the young olive tree is only such as becomes necessary to give a symmetrical top, the natural growth of the tree not being symmetrical. And Bioletti (764) found a very great reduction in growth of young olive trees caused by the pruning given in California for the purpose of obtaining vase formed trees. Yet unpruned trees four or five years old seemed to have better tops than had trees trained to the vase form. He recommends that trees five or six years old be thinned out by sawing out branches of considerable size.

With the persimmon, the fruit is borne laterally on current season shoots. According to Ikeda (837), as a tree becomes old and these shoots become very weak, the fruit may be small and worthless, or it may even fall off. In the case of a few varieties, only staminate flowers are borne on the weak shoots, pistillate flowers being borne only on rather vigorous shoots. It will be seen that as a tree grows older renewal pruning becomes essential in order to obtain shoots of sufficient vigor to fruit well. Ikeda gives an interesting account of the method by which the Japanese growers learned the value of renewal pruning. Much of the fruit is dried by being hung on strings. This process was facilitated by breaking off the shoot containing the fruit, the shoot being used to hang up the fruits. It was found that when this was done better fruiting shoots were obtained the next year. And, now, pruning is done by breaking off the shoots. Some prominent growers, instead of breaking back all the shoots, break off the terminal two years of growth from the longer branches. By this method, smaller branches back of the part removed are not broken off but are invigorated as a result of the removal of the part beyond them. This, of course, represents a renewal system much like that suggested as a thinning-back. It seems probable that such a cutting-back to laterals would be the most desirable method in this country.

Fig trees in California are generally cut back rather severely during the first few years in the orchard, but mature trees of the fig, the avocado, and the mango generally receive little pruning. Ryerson (1131) says that the young avocado trees should seldom be cut back, but in cases where branches do not start low enough on the trunk, it may be necessary to cut the whole top back to a strong dormant bud on the trunk. Cutting-back such trees to a branch has not been found to be a satisfactory means of forming a head. With most avocado varieties, cutting back the branches of young trees causes the growth of thick masses of vegetative shoots and delays fruiting more than it is delayed by cutting-back with most other kinds of fruit trees.

Nut trees are generally pruned very little, in so far as I am aware; and that is true of the English walnut (*Juglans regia*). However, Lewis (849a), from his experience in Oregon, recommends for that section that the trees be headed about thirty-five inches high, and that during the first summer a stake be driven close to the tree and four or five lateral branches that would form a good framework be tied to the stake, in order to keep them from drooping so much that they might later have to be removed. In succeeding years, while the tree is young, he recommends for these branches the same pruning that has been described for vase form apple trees. Of course, these recommendations are made from experience of a somewhat casual nature, rather than from extensively conducted experiments. According to Batchelor (939), there is a considerable amount of splitting down to be observed in some groves, and training to a head with strong crotches seems desirable. The central leader and the modified open head (the uppermost branch being kept the largest) are forms that may be desirable, but there is no experimental evidence concerning them. The old trees are generally pruned very little. But Batchelor thinks that since shaded branches soon come to be unfruitful some annual thinning-out of the branches may be desirable.

CHAPTER 19

PRUNING AND TRAINING GRAPEVINES AND SMALL FRUIT PLANTS

The grape. Some writers make rather sharp distinction between pruning and training, pruning being the cutting-away of parts in order to regulate the bearing of the vines, and training being the cutting-away of parts and disposing canes, vines, or stems in different directions, leaving them longer or shorter and in larger or smaller numbers, for the convenience of the grower's work. However, any cutting-away of parts, whether done for training or not, will influence the growth and bearing of the vines; and the number and length of canes as well as the direction in which they are tied will influence growth and bearing. In this discussion we are interested only in the behavior of fruit plants and shall study the responses to the various practices without reference to the purposes in the grower's mind.

Probably no other fruit approaches the grape in the severity of pruning which it receives. In fact, the amount of pruning commonly given the grape would make of most fruit trees a mass of water sprouts with little or no fruiting. This ability of the vine to withstand severe pruning has long been recognized. Hedrick (162) quotes from Dryden's translation of Virgil's *Georgics* (30 B.C.):

> "But when the rooted vines with steady hold
> Can clasp their elms, then, husbandman, be bold
> To lop the disobedient boughs, that strayed
> Beyond their ranks; let crooked steel invade
> The lawless troops, which discipline disclaim,
> And their superfluous growth with rigor tame."

The need of the grapevine for renewal pruning has been so long accepted that references in the literature giving experimental proof are very rare, though perhaps no other fruit crop has been so much studied experimentally as the grape. One recent experience is of interest. Varieties of the species *Vitis rotundifolia*, grown in the southeastern part of the United States, are rather new to cultivation. The growers of that region think that these varieties will not fruit well if pruned; yet Husmann and Dearing (836) have found that they fruit much better if they have rather severe pruning. The pruning can be much more severe with some varieties than with others. Bioletti (758) found that the short pruning generally given to many other Vinifera grapes in California reduced the fruiting of the Sultanina variety; and Barba and Chauzit (753) found less severe pruning to give a larger yield with some of the wine grapes of France. Zacharewicz (548) found that, when the canes were left from fifty to sixty centimetres long, the vines yielded about twice as much as when they were pruned to two buds.

Barba and Chauzit found that the quality of the wine made from grapes grown on the vines was not so high if more than the normal amount of fruiting wood was left. This seemed to be because the grapes did not mature so early. When the grapes on the long-pruned vines were harvested fifteen to twenty days after those on the short-pruned vines, the difference in the quality of the wine was not so great, though there was still some difference in favor of the more severely pruned vines. The more severe pruning probably improved the quality of the grapes by reducing the number of bunches to the vine. One of the most important benefits from pruning is in its reducing the number of bunches and thus increasing the size and quality of fruit borne; however, it does not follow that with all varieties the most severe pruning will, because of the smallness of the crop, cause the fruit to be of the highest quality.

Time of pruning. As to the time of pruning, grapes present a somewhat more complicated problem than do other fruits. While, with the common fruit trees, loss of sap from wounds amounts to little regardless of when the pruning is done, with the grape, if the pruning is done in spring or even in late winter, there may be very large quantities of sap lost. Newman (867) reports the collecting of twenty-three pounds of sap from a wound on a vine of *Vitis rotundifolia* that had been pruned in late winter. From casual observation one would think that such loss of sap might be seriously injurious to the vine. Clark (794), however, reported analyses of the sap lost in bleeding from *Vitis Labrusca,* which indicate that it contains practically no carbohydrates. He therefore concluded that it represents very little drain upon the plant. Some experiments were undertaken in the vineyard of Cornell University with Concord grapes (*Vitis Labrusca*) to determine if possible the effect of pruning late enough in spring to cause copious bleeding on the vigor of growth and yield of the vine. The soil was not so uniform as might have been desired, and the experiment, after a few years, was discontinued. The results suggested, however, that if there is any bad effect from pruning late in spring, it is too small to be measured under average vineyard conditions. Although there was much bleeding from late pruned vines, no influence on the time of starting growth was observed. More conclusive results were obtained by Gladwin (815) with the same variety. With each of six forms of training he pruned one half of the vines in early winter and the others about two weeks before the leaves were opening. The six year average yield did not show differences large enough to be significant, though the difference was generally in favor of the spring pruning. Gladwin observed at Fredonia, New York, that vines pruned still later, after growth had started, had more buds uninjured by a spring freeze than had vines pruned earlier. The uninjured buds were not so far advanced in development when the freezing weather came. With *Vitis rotundifolia,* however, Newman (867) found a vine pruned in February ten days later in putting out its leaves, and much more feeble in growth, than one pruned in November. There was copious bleeding from the vine pruned in February and none from that pruned in November.

Ravaz (878) seemed to find the vigor of Vinifera grapevines reduced when the pruning was done late in the spring, at the time when the buds farthest out on the canes were bursting, and, more strikingly at the time when these were about five centimetres long. The time of opening of the buds left and of blooming was also delayed. It is not indicated that this was caused by bleeding, however. In fact, the evidence is not strong that the vigor was actually reduced. Some of the vines pruned late had a slightly smaller annual growth, but they had a slightly larger yield. Naturally an increased yield would be expected to reduce the growth. Bioletti (759) obtained, at Davis, California, results agreeing with those of Ravaz in respect to the effect of late pruning on the time of opening of the buds and of blooming; but he seemed to find that the later blooming tended to encourage the setting of larger crops of fruit.

Vidal (910) seemed to find, at one place in France, a reduction in vigor as the vines were pruned later in the season, while at another the greatest vigor seemed to come when the pruning was done as late as April 1st. There was a marked decline in vigor when the pruning was done as much as two weeks later; but we should expect a weakening of the vines as a result of pruning done after a considerable amount of growth had taken place. Of these experiences, the delay which Newman observed in the starting of shoots of *Vitis rotundifolia* caused by pruning in spring instead of winter seems to have been due to the bleeding; yet the November pruning may have hastened the ending of the rest period. It is said that in southern France the basal buds are delayed in starting if in pruning there are left beyond the last bud several joints of cane with the buds removed. We have seen that pruning may hasten the ending of the rest of the bud near the cut surface; and it seems probable that, by making that cut surface the length of several joints beyond the last bud to be left, such an influence on the rest period may be reduced. While in warm climates with short winters the earlier starting of the buds on vines pruned in winter or very early spring may be due to an influence of pruning on the rest period, the delay in starting that, in New York, Gladwin found to follow very late pruning cannot be explained in that way; for in New York the rest period is ended long before either the early or the late pruning. In that work the pruning that delayed growth was done after buds toward the ends of the canes had started to grow; and the delay in the basal buds may have been an expression of polarity, the growth from the basal buds being inhibited until the distal growing buds were removed. In fact, even the leaving of several disbudded joints of canes beyond the last bud may delay the starting of the buds by the same influence that determines polarity rather than by breaking the rest. However, with Labrusca grapes in the latitude of New York, the starting of basal buds may not be delayed by pruning late enough to cause loss of sap from the wound, provided the pruning is done before shoot growth has started. At least this seemed to be the case in the Cornell University orchard.

In colder climates, even if it were found that pruning as soon as the leaves were off or during early winter slightly increased the vigor of the vines, it would still be better to delay it until after danger of severe freezing had passed. Uninjured canes could then be chosen to leave for fruiting.

Summer pruning and pinching. It is often recommended that, in addition to the pruning done during the dormant season, the new shoots formed be cut back or the growing tip be pinched off in summer. Various benefits are supposed to follow such pruning. One sometimes claimed for it is that by checking the growth at the end of the shoot the bunches of fruit are stimulated to better development. It seems possible, too, that if this pinching were done about the blooming time, nutritional conditions in the shoot might for a short time, before a new growing point became very active, be more favorable for the setting of fruit from the blossoms on the shoot pinched. Guillon (822) seemed to find that this may be true. Thus with his vines receiving short cane pruning, when the ends were pinched off two leaves beyond the last flower cluster, the yield seemed markedly increased, but the shoots were stimulated to branch too much. On the secondary shoots many grapes were set and these did not mature. Pinching on June 16th, just before the bloom, did not encourage such thick growth of shoots or the setting of grapes on lateral shoots, and yet it encouraged a large percentage of the flowers on the main shoot to set fruit, and caused the best yield. Topping back the shoots July 4th and August 22d also seemed to stimulate increased yield. It is possible that pinching July 4th, just after the bloom, may have increased the percentage of the flowers to set fruit though it seems hardly probable that pinching as late as August 22d could have had that effect. It is conceivable that pinching at either time may have caused the individual berries to be larger. These results were for one year only, however; and not enough information is given as to just how the plats and the checks were disposed in the planting. The difference may have been within the range of experimental error.

Riviere and Bailhache (888) found that if the shoots are pinched too short, the sugar content of the grapes is reduced. When but one leaf beyond the last cluster of grapes was left, the percentage of sugar in the fruit was smallest; and that percentage increased for each additional leaf to the shoot left, up to six or seven leaves beyond the last cluster.

Bioletti and Flossfeder (760) did some rather comprehensive experiments with topping and pinching grapevines in California, using two hundred and twenty vines of the variety Carignane and two hundred and forty of the variety Tokay. Each treatment was on two plots of each variety. Thus the experimental error should be rather small. With both of these varieties the vines tend to bear heavy crops regularly. In pinching, only the extreme tip of the shoot was removed. In topping, one fifth to one fourth of the length of the shoot was cut off. Both pinching and topping reduced the yield and vigor of the vines, though topping caused the greater reduction. With some of the vines, pinching was done but once in the season while with others there were three successive pinchings in a summer. After the first pinching, new shoots would grow from buds near the pinched end, and after the second pinching other shoots, which were also pinched. With Carignane in the first year of the experiment, pinching once seemed not to influence the weight of the first-crop fruit, but slightly to increase the weight of second-crop fruit borne; while pinching three times seemed to reduce the yield of first-crop fruit and slightly to increase the yield of second-crop fruit. The differences may have been within the range of experimental error. With Tokay, it is not certain that pinching influenced the yield in the first summer. With both varieties, the yield in the second summer was reduced by the pinching. Pinching three times caused the greater reduction. With topping once, the yield in the first summer was not significantly influenced in the case of either variety, though topping three times seemed to reduce the yield. With both varieties, the yield in the second summer was reduced more by topping than by pinching. The reduction in yield in the second summer seems to have been in proportion to the reduction in vigor of the vines. With Carignane the percentage of sugar in the fruit was reduced by pinching. By second-crop grapes is meant those borne on the lateral shoots; that is, the shoots that branch off from the main shoots of the same year. Naturally, pinching increases the number of lateral shoots by encouraging buds to grow that would otherwise remain dormant until the next season. It would, therefore, be expected to increase the amount of this second crop. Bioletti and Flossfeder say that some varieties of Vinifera grapes fruit mainly on the lateral branches. In the case of such varieties, it would seem probable that pinching once might increase the yield unless it too greatly reduced the vigor of the vines. They suggest that pinching might be desirable with varieties that tend to extend their energies in wood growth rather than in fruitfulness. It would seem probable, however, that a more effective method would be to reduce the vigor of the individual canes by leaving at dormant pruning a larger number of buds to form canes.

With both Carignane and Tokay, the flowers seem to set well, the bunches being compact; and pinching could have increased the yield of first-crop grapes only by causing the berries to be larger. If varieties had been used with which an undesirably large percentage of the flowers fail to set fruit, the bunches thus being loose and light, it is conceivable that the pinching would have caused more flowers to set fruit and, therefore, heavier bunches.

Whether or not the above results with Vinifera grapes would apply also to Labrusca grapes grown in northeastern America, we cannot say; but it would seem wise to omit such summer pinching or topping until there is evidence that it is beneficial. Of course, where the foliage is so dense as to encourage mildew or other diseases, it may be wise to remove some of the shoots in order to dry off the fruit earlier in the morning and perhaps avoid the loss of the crop.

Systems of training for Vinifera grapes. In discussion as to training, the following terms are used: shoot, current season's wood, bearing leaves and sometimes flower or fruit clusters; cane, the previous summer's wood from which the leaves have fallen, and which contains the buds; spur, a short stub left from a cane and containing only a few buds; arm or branch, a short or long division of the trunk, at least one year older than a cane.

It does not seem necessary to discuss minutely the various details of training grapes or to discuss all the various systems, particularly with the varieties of *Vitis vinifera*, which, though of much the greatest importance, are grown in so many countries with different local practices that a discussion of the problems involved with each practice would be too voluminous for any one person's interest. Vidal (909) says that the various training systems used in France may be divided into two classes, those which leave the canes long and those which leave them short. He describes some of the leading systems used in France as follows:

> The *gobelet* is the type of the short prunings on short framework, to which can be connected all the systems of this category, with one or several arms.
>
> The *Guyot* is the typical example of the forms with long wood on a short framework. The elements can be doubled, arranged in different manners, take different names, the principle remains the same.
>
> The simple *Cordon de Royat* and the pruning *Chablis* are the systems to which are related all the short prunings on a long framework, with stubs distributed along the arms for the first, and with multiple arms bearing single terminal stubs for the second.
>
> The *Cazenave* is an example of the systems with long canes on a long framework.

Vidal (909) reports some experiments with vines of the varieties Folle Blanche and Colombard pruned to goblet, Guyot, and cordon. Each plot contained twenty-four vines of each variety. The vines of each plot were grafted on twenty-two different stocks; but the same twenty-two stocks were apparently used in each plot. The average annual results for six seasons are summarized in Table 60.

TABLE 60. EFFECT OF SYSTEM OF TRAINING UPON YIELD AND MATURITY OF VINIFERA GRAPES

VARIETIES AND TRAINING SYSTEMS	WOOD LEFT		BUDS TO THE PLANT LEFT	BUDS TO THE PLANT DEVELOPED	YIELD TO THE PLANT (kg.)	DENSITY OF JUICE
	Spurs	Canes				
Folle Blanche						
Goblet	3.00		9.00	7.50	0.592	1.0775
Guyot	1.00	1.00	12.00	10.25	1.418	1.0719
Cordon	5.25		11.50	10.50	1.627	1.0727
Colombard						
Goblet	3.25		9.75	8.50	0.984	1.0787
Guyot	1.00	1.00	13.00	10.00	1.731	1.0767
Cordon	5.00		12.00	10.75	1.719	1.0773

It will be seen that the goblet form has yielded less than either the Guyot or the cordon, and the difference is greater than would be expected from the difference in the number of buds left. Evidently the shoots were less fruitful with vines pruned to the goblet form (short spurs on head). The smaller yield of the goblet form must not have resulted merely from the fact that short spurs were used; for the cordon system yielded as much as the Guyot and short spurs were used with it also. It may be that, since fewer canes grew with the goblet system, they were longer and the buds at the base, which would be left on the spurs after pruning, weaker. We have seen, however, that some workers found the wine from long pruned vines of poorer quality; and in this work Vidal seemed to find the juice of grapes from goblet pruned vine to have slightly the greatest specific gravity. In other words, reduction of the yield seemed to increase the sugar content.

Vidal found the cordon pruned vines to increase in vigor from year to year, while the Guyot pruned vines diminished. Perhaps this may be due to the training of the canes toward the horizontal in case of the Guyots. On the other hand, the cordons were least resistant to drought; and the vines that gave the best results trained as cordons were those on the stocks that are most resistant to drought. The amount of fruit borne from a spur is much less than that from a cane, which fact may account for the greater vigor of goblet and cordon vines and for better quality of fruit with some varieties. Vidal found the fruit to ripen better on the cordon than on the Guyot system, and with some varieties better than on the goblet system. This was particularly true in years when the leaves had been injured. He thinks that the better ripening of the fruit on cordons is because the larger amount of wood in the arms makes possible a larger food reserve.

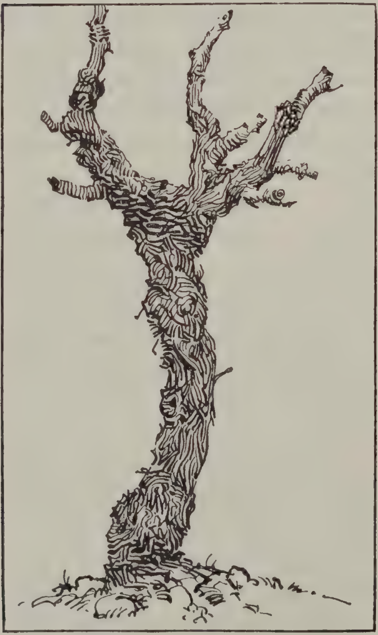

Figure 36. Head or goblet pruning. (After Bioletti.)

Moreau-Berillon (863) describes an interesting custom that prevailed in the Champagne region of France before the introduction of the Phylloxera made it necessary to grow Vinifera grapes on resistant roots. The vines were buried except for the fruiting canes which emerged from the ground and were tied to stakes. Usually there was one cane to the vine though sometimes two were left. There resulted from this a veritable network of underground branches. When grafting on resistant stock first became necessary, wineries discriminated in favor of the grapes grown on the old layered vines, the grapes seeming to be better ripened. Vidal thinks that this underground network of branches may have been a means of storing food reserves that would insure better ripening in unfavorable years. He thinks the fact that these branches come to behave as root tissue would increase their value as reserve tissue, since, as he thinks, root tissue more readily gives up its reserve carbohydrates. He reaches this conclusion from some analyses which indicated that roots decrease in carbohydrate percentage during the ripening of the fruit, especially when the crop is heavy, while the percentage in the wood above ground increases. Of course, such analyses should be made from very many plants before one would be justified in reaching such a conclusion. Further, even if this decline in carbohydrates in the roots were found uniformly to occur, it is possible that it is being used for root growth, and not more largely for the ripening of the fruit than is the carbohydrate reserve of the aerial part of the plant.

Bioletti (759, 765) describes for California growers, "head pruning," "cane pruning," and horizontal cordon pruning, which systems resemble respectively goblet, Guyot, and cordon pruning of the French growers. He says that "head pruning" is desirable for varieties such as Muscat, Verdal, Tokay, Black Prince, Mission, and Malaga that can be grown without trellises; it is the system most easily established and permits of cross-cultivation; cane pruning is necessary for varieties such as Sultanina and Sultana; cordon pruning is desirable for varieties such

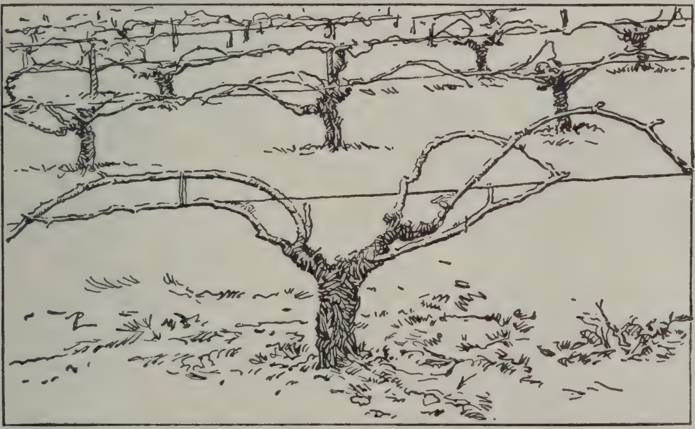

FIGURE 37. Cane pruning. (After Bioletti.)

as Emperor and Cornichon and other vigorous large-fruited table grapes that will not bear enough fruit with head pruning, and bear fruit of inferior quality with cane pruning. With cordon pruning, nearly all varieties will start good fruiting shoots from the lowest buds of the canes. The cordon system is the most laborious to establish, but is the simplest to maintain after it is established. Of course, with head pruning the spurs are left longer with some varieties than with others, or with some soil conditions than others, or more spurs are left; with cane pruning the length and number of canes and to some extent the disposition of the canes on the trellises, whether upright, curved, or horizontal is determined by the nature of growth of the variety or by the soil or other vineyard condition; and with cordon pruning there may be adjustments of the number and length of spurs to the variety or to soil or climatic conditions.

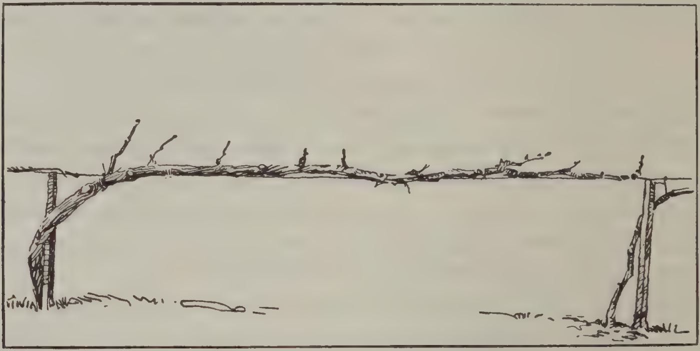

Figure 38. Cordon pruning. (After Bioletti.)

Systems of training for American grapes. With varieties of *Vitis labrusca,* as with those of *Vitis vinifera,* the length of cane seems to be of importance. There has been less study than with *Vitis vinifera* varieties. Keffer (843), working in Tennessee, reports results of one season's study which suggest that the basal two or three buds on a cane give less productive shoots than those farther out. This suggests that with Labrusca varieties spur pruning may be undesirable because of the weak fruitfulness of buds at the bases of the canes. Maney (860), working in Iowa, published, for one season's work with Concord grapes, results which indicated that having several canes each containing eight or ten buds would increase the yield as compared with vines on which were left considerable numbers of spurs each containing only two or three buds. If about the same numbers of buds were left on pruned and unpruned vines his results are in agreement with those of Keffer, indicating that buds farther from the base than can be left in spur pruning are more fruitful than basal buds.

Partridge (871) found basal buds on canes of Concord grapes less fruitful than buds farther out on the canes. The amount of fruit borne by a shoot from a bud was greater between the fourth and ninth buds from the base. However, beyond the basal two or three buds, the length of cane he found it desirable to leave was not determined alone by the position of the most fruitful buds. He found the type of cane having the most fruitful buds to be one about one-fourth to three-tenths of an inch in diameter, measured between the fifth and sixth buds from the base. If too many buds were left few canes would be as large as this in the following year. In the climate of Michigan with the average soil the best results were obtained when eight to eleven buds were left on each cane. In very rich soil more buds to the cane gave good results; but better results were obtained by leaving more canes, rather than longer ones, on such vigorous vines. Schrader (893) obtained results in Maryland in general agreement with those of Partridge. Under his conditions the best fruiting shoots came rather consistently out of the fourth bud from the base of the cane. The results of these experiments seem to be in agreement with the experience of growers; for in most Labrusca grape growing sections cane pruning rather than spur pruning is practiced.

There are many systems or styles of training American grapes. Usually some one system prevails in a given locality. The history of these systems has been given by Bailey (749) and also by Hedrick (829), and so it does not seem necessary to stress that here. Hedrick describes among others the following systems: the Chautauqua Arm, Keuka High Renewal, Kniffin, Munson, and Fan.

By the Chautauqua Arm system, arms are fastened to the bottom wire, and, with mature vines, about four canes are taken from these and tied up to the top wire each spring. Of course, spurs are left near the arm, from which to obtain canes for the following year.

By the Keuka High Renewal system, a cane is trained out each way from the trunk, along the bottom wire, and with more vigorous vines another may be trained diagonally to the second wire. The shoots are then tied up in the summer to the top wire.

By the Kniffin system there may be two canes, one trained each way from the trunk on the top wire, or there may be four canes, two each way from the trunk on separate wires; or, in case of exceedingly vigorous vines, like the Southern Rotundifolia grapes, there may be three each way from the trunk. There are sometimes used the Two-Stem Kniffin, with which there are two trunks, one with a cane each way on the top wire, and the other with a cane each way on the lower wire, and the Umbrella Kniffin, by which there is a cane starting each way on the top wire but trained diagonally downward to the other wires. Of course, two spurs are left at the top from which to grow canes for the following year. According to Gladwin (815), the tendency with this system is for the best shoots to grow from near the head of the vine and in the bends of the canes; while with the Kniffin proper, with which the canes are not bent but are tied straight along the wires, the shoot growth from the different buds is more nearly uniform.

The Munson system, by which the canes are trained each way along a central wire, and the shoots are trained in summer out to the right and left over parallel wires, fastened to the end of cross-bars at the top of the posts, is a modification of the Kniffin system. Except with young or weak vines usually two canes are trained each way, and tied to the one central wire.

By the Fan system the canes are trained out fan-shape to the two or three wires that may be used, the renewal being very nearly to the ground. Spurs, of course, are left from which to obtain canes for the following year.

With all of these systems it would seem that the physiological response of the vine is involved less than are convenience and cheapness of operation. The habit of the grape shoot in bearing fruit clusters only at the basal four or five nodes is of importance with the Fan system, the fruit for this reason being borne so near the ground that it is damaged by the splashing in the rains. This, together with the large mass of spurs near the ground, which interferes with cultivation, has prevented the extensive use of this system. With the High Renewal system, physiological response may be involved through the reduction in the amount of old wood with its resistance to the movement of water and nutrients (if these resistances are important), and through the upright training of the shoots. Bioletti (759) and Hedrick (829) say that experience indicates that the nearer the shoot or cane approaches the vertical the more vigorous will be the growth. Mr. A. M. Burroughs in some unpublished work seemed to find experimental evidence that this may be true. If upright training of shoots or canes increases vigor, then vines trained to either the High Renewal or the Chautauqua system should tend to make greater wood growth than vines trained to the Kniffin systems. Gladwin (815) publishes some results which indicate that this is true, at least with the Concord grape. However, the vines in the High Renewal system yielded less than those in the Kniffin systems and this may account for the difference in growth. His results as to yield and growth with the different forms that he tried are shown in Table 61.

TABLE 61. THE EFFECT OF DIFFERENT SYSTEMS OF TRAINING ON THE GROWTH AND YIELD TO THE ACRE OF CONCORD GRAPES IN NEW YORK

SYSTEM OF TRAINING	PRUNINGS (6 yr. av. lbs.)	YIELD (8 yr. av. tons)
Munson	1533	3.57
Single-Stem Four-Cane Kniffin	1327	3.91
Chautauqua	1497	3.69
Umbrella Kniffin	1333	3.52
High Renewal	1529	2.68
Two-Stem Kniffin	1207	3.34

The High Renewal system is much the lowest in yield, though high as to amount of wood pruned away; and the Two-Stem Kniffin is rather low. Among the others it is doubtful if the differences are significant. The yield of some of the forms, such as the Munson, could probably have been increased by leaving a little more wood. In fact, after three years, the amount of wood left with the Umbrella Kniffin was increased, after which time the yield with that form was about equal to the yield with any other form. The fruit matured best and the bunches were the largest and most compact with the Umbrella Kniffin. There was little difference in maturity or in size of bunches between the Chautauqua and the Single-Stem Kniffin, and the Munson was nearly as good, but the High Renewal and the Two-Stem Kniffin were much below the others.

Auchter and Ballard (747) studied the response of several varieties of Labrusca grapes to different training systems. Their results as to yield are summarized in Table 62.

TABLE 62. THE EFFECT OF DIFFERENT SYSTEMS OF TRAINING ON THE YIELD TO THE ACRE OF SEVERAL VARIETIES OF LABRUSCA GRAPES IN MARYLAND

SYSTEM OF TRAINING	WORDEN 4-YEAR AVERAGE (tons)	CONCORD 4-YEAR AVERAGE (tons)	LUTIE 4-YEAR AVERAGE (tons)
Single-Stem Four-Cane Kniffin	4.63	4.92	3.86
Single-Stem Two-Cane Kniffin	3.00	3.40	2.92
Munson	4.34	4.52	4.10
Two-Wire Umbrella Kniffin	3.40	3.84	3.09
Fan	3.90	4.07	3.49

The Single-Stem Four-Cane Kniffin seems to be slightly better than the Munson system which is next best of the methods used in the experiment. With the Two-Cane Kniffin and the Umbrella Kniffin, an effort was made, by leaving the canes longer, to leave as many buds as were left by the Four-Cane Kniffin and the Munson systems. However, this was not always possible and it seems that the lower average yield of the vines trained to these forms is due to the smaller number of fruitful buds left. If training the canes in an upright position tends to increase vegetative growth and to reduce fruitfulness, it is possible that the slightly smaller yield with the Fan system may be explained by that principle. For Labrusca grapes grown in good soil, it seems probable that, all things considered, a Kniffin system (the Two-Cane or the Umbrella for conditions in which the growth is weak, and the Four-Cane for conditions in which the growth is vigorous) gives in general the most satisfactory results, though there is little difference in yield among the systems that have as much as four canes extending nearly halfway to the stem of an adjacent vine. With other American species, also, the Kniffin system seems desirable, but with the more vigorously growing species, long canes and more than four to the vine may be desirable.

It has been the practice of farmers growing Rotundifolia grapes to train them on arbors made of overhead horizontal cross-wires. Husmann and Dearing (836) find that training by the Kniffin system, but using at least six rather long canes, seems to give about as good results; and the investment for trellises is from ten to twenty dollars an acre less. The Munson system, while being nearly as good as any of the others in its influence on yield, generally is impractical because of the expense of making the trellises.

In plantings for home use it is often desired to have the vines cover a porch or an arbor. Under such conditions no particular system need be followed; the only precautions that must be taken are to give a large amount of renewal pruning and to leave enough canes to produce a desirable crop. Vines do not have to be kept as small as those found in a vineyard. Thus I have seen a Moore Early vine covering a trellis ninety feet long by about fifteen feet wide, and yet bearing bunches of grapes nearly as good as those commonly borne in the vineyard. It would seem wise under such conditions for the grower to be guided in his pruning by the bunches of fruit obtained. If in any year the berries or clusters are smaller than they should be, the following year fewer canes or shorter ones should be left. Of course, before the vine has covered the trellis there must be some renewal pruning, or the berries will be poor and the vines weakened; but increased amounts of cane wood can be left each year until the trellis is covered.

Maturity of the fruit may be hastened by training against the south side of buildings or walls, and in sections where the summers are a little short for the ripening of certain varieties before the fruit is in danger of being injured by frost, such positions are very desirable.

It does not seem necessary to discuss the training of the young vines before they reach bearing age, since the student is assumed to be acquainted with those details. From what we have seen concerning the dwarfing effect of severely pruning young trees, we may be led to question whether the very severe pruning of young grapevines may not delay the vine in reaching profitable bearing. Thus, if one is training to the Kniffin system it is necessary to get a trunk to the top wire. May it not be possible by leaving the strongest cane that grows the first year (instead of cutting it back to a single bud) to increase both root and top growth and more quickly to obtain a vine capable of bearing a profitable crop. Of course, if the vine should bear fruit during the second summer, the dwarfing effect of the fruiting might offset the benefit from the larger foliage. At any rate it is better to follow current practice until there is conclusive experimental evidence favoring a different course.

Planting distances in relation to training. The question of planting distances is closely related to that of pruning. Convenience of working as well as the requirements of the vine will determine planting distances. In the Labrusca grape region of northeastern United States, the rows are eight or nine feet apart, with the plants from six to eight feet apart in the row. Vinifera grapes in some European sections are often planted closer; but in California the tendency is to set plants of most varieties farther apart. With both, the fruiting habit of the variety will have an important influence concerning planting distances, the more vigorously growing ones requiring the greater distances in order that longer canes may be left. It is possible that with any variety, after it has been a considerable number of years in the vineyard, the distances between the plants in the row could be greatly increased over that commonly used, without reducing the yield. Thus, according to Ikeda (837) in sections of Japan, grapes may be planted so far apart that there are but forty vines to the acre, the canes being trained very long on overhead trellises; yet excellent results are obtained. Of course, after the vines have covered the trellises, as large a percentage of each year's growth can be removed in pruning as if they were shorter, but less pruning must be done while the vines are young, so that they may gain in size each year until the trellis is covered.

Vidal (909) found for varieties of Vinifera grapes grown in France, and trained to the goblet system, that rather close planting gave the best yields to a given area during the first five bearing years. While it seems possible that increasing the planting distance might not reduce the yield of mature vines, it seems certain that planting as close as it is possible to plant without inconvenience in working and without making the canes too short to include the most productive buds, may be expected to increase the yield of the vineyard during the first few bearing years; for the vines would more quickly occupy all space available. It would also seem probable that rather close planting might help to insure the maximum bearing of the vineyard throughout its productive life. For, if a vine dies or becomes very weak, with close planting, the canes from the neighboring vines may be left enough longer than they ordinarily would be that their increased production may almost compensate for the loss of the vine. Bioletti (766) found that with Muscat, a weak growing variety suitable for head pruning, the average yield of vines next to a vacancy was 10.1 per cent greater than the average yield of vines surrounded by other vines; while with Sultanina, a vigorous variety requiring trellises, the yield of vines next to a vacancy was 21.7 per cent greater than that of vines surrounded by other vines. With head pruning it may not be as convenient as with cane pruning to leave more wood next to a vacancy and have it occupy the space to the best advantage. It is probable that if these planting distances had been smaller and special attention to having more wood on vines next to a vacancy had been taken there would have been even greater increase in yield of vines next to a vacancy.

Gooseberries and currants. Both gooseberries and currants can be trained to tree-like forms; and gooseberries are sometimes trained as espaliers. They naturally form bushes, however; and under commercial conditions it seems better to grow them in that way. From Pickering's findings, which we have studied in an earlier chapter, where Paradise apple trees, which root readily from the wood, were planted deep and had the growth markedly increased as a result of the increased root system, we should expect that planting gooseberry and currant plants deep enough for some of the branches to be covered with soil and to form roots might appreciably increase the growth, at least during the first few years in the planting. Having a number of rooted branches is a valuable precaution particularly with the currant, since at certain times in the summer its wood is very brittle. With a bush composed of a number of rooted branches, the loss is not so great when one is broken off. Gooseberries and currants are planted four to six feet apart; and, in good soil, the plants will eventually become so large and crowd each other so that there will be injury to some of the wood from the shade; working among them will be inconvenient; and the color of fruits will be less brilliant. Some cutting away of the most widely spreading branches would be necessary for that reason alone.

With both gooseberry and currant plants the fruit is borne toward the base of the wood one year old, and on spurs from older wood. Generally better fruiting spurs come from long vigorous twigs and the spurs do not fruit well after they are more than two years old. The twigs at the end of old branches are generally short and weak. The better growth comes as new shoots from near the ground or beneath it. It is generally recommended, therefore, that the pruning be a cutting-away of this older wood, leaving branches containing vigorous wood, one, two, and three years old. Some growers say that with the currant, particularly, the fruiting is much better when the vines are pruned severely; and Lees (849) says that with the best pruning methods with the black currant in England no four-year-old wood is left. Black currant bushes generally require more pruning than do red and white currant bushes. Under some conditions, particularly with black currants, some of the new shoots may be thinned out. The fruit of all kinds will generally be larger if some of the branches one year old are thinned out; but increase in size at the cost of such pruning and reduced yield may not be profitable.

Many currants are grown in New York, and, if I can trust my observations, the larger number of plantings do not receive much pruning. Neither the currant nor the gooseberry is a crop that will generally return good profits on a large expenditure of labor; and so even though it might be certain that such renewal pruning as that described above would maintain the planting at a higher productivity, or result in better fruit, we need the results of careful experiments as to the response of these plants to pruning before we can say with any degree of certainty whether the benefit is large enough to justify pruning carefully every year rather than once in two or three years. Local price conditions will determine whether much or little care is most profitable; but if we knew, for average soil and climatic conditions, the amount of benefit that one might expect from pruning, decisions as to what would be profitable for any given set of conditions could be more wisely made.

Raspberries and blackberries. With black raspberries it is a very general custom to pinch the growing points off the young shoots when they are fifteen to twenty-four inches high, or to top them back to about that height if they have grown considerably taller, thus causing them to form a number of branches low on the shoot. If the canes are not trained on trellises, this practice is necessary in order to keep the bearing plants in a manageable condition, and particularly to keep the berries out of the mud; for without the pinching a considerable percentage of the crop would be borne toward the end of long trailing canes. Since red raspberry canes generally stand erect, pinching is not necessary for convenience in managing the planting, and is not generally practiced. As to whether or not such a practice may be expected to increase the yield even in the case of black raspberries, we have hardly sufficient data for a conclusive answer. Goff (819, 820) and Cranefield (799) have published the results of some pinching tests with the Gregg black raspberry and the Cuthbert red raspberry. There were approximately 36 plants receiving each treatment. In Table 63 is summarized their results, as to yield during four years.

TABLE 63. EFFECT OF PINCHING OFF THE TIPS OF SUCKERS ON THE YIELD TO THE ROW OF THIRTY-SIX PLANTS OF RED AND BLACK RASPBERRIES

CUTHBERT RED RASPBERRY

TREATMENT	AVERAGE YIELD OF 4 SEASONS (ounces)
Shoots not pinched	970.2
Shoots pinched at 12 inches	830.5
Shoots pinched at 12 inches — laterals at 12 inches	857.7
Shoots not pinched	996.4
Shoots pinched at 18 inches	864.7
Shoots pinched at 18 inches — laterals at 12 inches	908.3
Shoots not pinched	773.4
Shoots pinched at 24 inches	992.9
Shoots pinched at 24 inches — laterals at 12 inches	773.7

GREGG BLACK RASPBERRY

TREATMENT	AVERAGE YIELD OF 4 SEASONS (ounces)
Shoots not pinched	954.7
Shoots pinched at 12 inches	795.1
Shoots pinched at 12 inches — laterals at 12 inches	1118.7
Shoots not pinched	814.1
Shoots pinched at 18 inches	1150.8
Shoots pinched at 18 inches — laterals at 12 inches	1046.6
Shoots not pinched	952.8
Shoots pinched at 24 inches	1261.4
Shoots pinched at 24 inches — laterals at 12 inches	1182.4

It will be seen that with the Cuthbert in the climate of Wisconsin the pinching seems certainly to have been injurious. This would not necessarily apply to sections where the summers are longer and there is time for the branches resulting from the pinching to form strong buds. With the Gregg, while the results are hardly conclusive, they suggest that, when the shoots are permitted to become from eighteen to twenty-four inches long before pinching, the yield is slightly increased by the process. However, when the pinching was done at twelve inches, the yield seems certainly to have been reduced.

Since the new branches on the pinched black raspberry canes are long and rather slender toward the end, it would seem highly probable that the yield would be improved by having these branches cut back, so that the fruit may be borne only from the stronger buds and on parts of the plant that stand erect so that the berries will be kept off of the ground. I know of no experimental data, however, concerning this point.

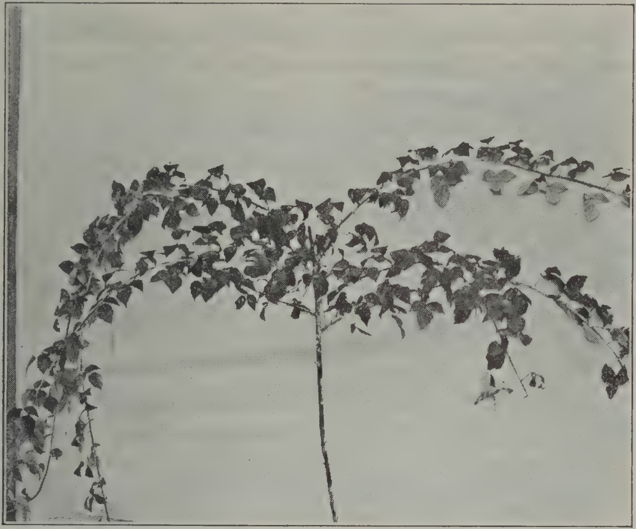

FIGURE 39. Black raspberry shoot showing the nature of the branching caused by pinching off the terminal in early summer.

In some sections where climatic and soil conditions are favorable to very long cane growth, red raspberries are trained upon trellises. The canes then may or may not be shortened back. Darrow (802) describes various methods by which the canes are disposed on the trellises. There is no published evidence to indicate that any of these methods will influence the yield. It seems probable that tying the cane down along a wire might increase the number of shoots that would grow on a cane without any appreciable inhibitive influence from apical shoots; possibly without reduction of the vigor of the whole plant. However, we cannot be certain of this until we know more about the influence of responses to polarity on the growth of the plant as a whole. Certainly if tying down to wires should increase the bearing surface and the leaf surface of fruiting canes, there would have to be an abundant water supply if the fruit were not to be of reduced size. It may be that such tying down does not increase the yield or that it even reduces it, but causes harvesting and cultivation to be less expensive or less injurious to the canes.

Many growers in the northeastern part of the United States do not use trellises, but shorten the canes back to a considerable extent each spring. When the canes are thus shortened back the flower bearing shoots are longer, and there seem to be more berries to the cluster. The berries are also certainly larger than those formed on shoots from buds toward the top of unpruned canes. As to whether or not they are enough larger and there are enough more berries in a cluster actually to increase the yield, we cannot say from conclusive experimental evidence. In a Cuthbert raspberry planting, on the Cornell University grounds, containing thirty-six rows, each representing approximately one fiftieth acre, half of the rows had the canes pruned back to three and a half feet in height. In Table 64 is given the yield in the summer preceding and in the summer following the pruning.

TABLE 64. EFFECT OF PRUNING ON YIELD OF CUTHBERT RED RASPBERRIES.

TREATMENT	1918		1919	
	YIELD TO THE ROW (pounds)	YIELD TO THE CANE (pounds)	YIELD TO THE ROW (pounds)	YIELD TO THE CANE (pounds)
Unpruned	35.7	.118	22.3	.089
Pruned spring, 1919	33.8	.117	22.3	.096

We cannot say with certainty that the pruning has increased the yield, though it seems certain that it has not reduced it. For the pruned rows had, in the previous year, when all had the same treatment, given slightly the smaller yield, while in the year succeeding the pruning they gave slightly the larger yield to the cane. The planting suffered from the effects of very dry weather; and so the benefit from the reduction in water loss caused by pruning was probably slightly greater than it would be in an average year. Since the berries are a little larger and in larger clusters, and picking is more conveniently done with pruned canes, it seems desirable to prune, even though the influence on the yield may be very slight.

It seems remarkable that pruning should not reduce the yield, since the active buds were more numerous towards the top of the canes. Unquestionably with many of the larger, stronger canes much more than half of the buds that would have opened had there been no pruning were removed. It seems probable that some buds which would not have opened into fruiting shoots must have done so under the stimulus of the pruning. And McDaniels (222) found that all, or nearly all the buds on raspberry canes are potential fruit buds. Although many toward the base remain dormant on unpruned canes, if pruning is severe enough, buds to the very base of the cane may grow and usually bear fruit.

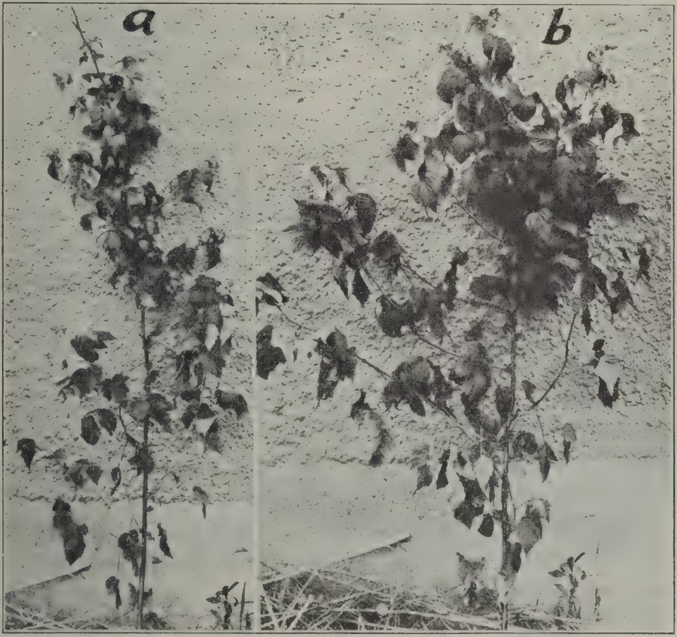

Figure 40. Red raspberry canes, *a*, unpruned and, *b*, pruned. Note the much greater length of fruiting shoots on the pruned cane.

With many varieties of red raspberries, when the soil is fertile far too many canes are formed. We have seen that when the planting is fertilized with nitrogen the increase in yield is slight in comparison with the increase in the number of canes; and the yield to the cane is strikingly reduced. It seems probable, therefore, that better fruiting would result if many of the shoots were removed soon after they started in summer. Where the canes are trained on trellises, and it is desirable to have them very long, this is generally practiced. And some growers in sections where trellises are not used seem to obtain larger fruit and apparently larger yields by practicing such thinning-out of shoots.

One method of reducing the crowding of the canes is to have the planting in hills, so that it can be ploughed in both directions. This should tend to increase the yield from the individual canes, and should greatly reduce the labor cost of maintaining the planting. Since with small fruits the labor cost is many times that for rental on the land, it would seem probable that such a system might be wise, even though it should reduce to some extent the yield to the acre.

With blackberries trailing forms, such as Evergreen and Mammoth, are trained on trellises, but other varieties are commonly pruned very much as black raspberries are, the shoots, except where trellises are used, being pinched in the summer in order to cause them to branch, and the branches being cut back in the spring pruning. We have no experimental evidence concerning the effect of this practice on the yield. Without the pinching, however, the canes become unmanageable; and experience indicates that without the cutting-back the berries may dry up badly in case of a drought during the picking season. How severe such pruning may be without reducing fruiting we do not know. McDaniels found with the blackberry as with the raspberry that such cutting-back causes buds that would otherwise remain dormant to grow and produce fruit; though, with the blackberry more often than with the raspberry, basal buds when forced by pruning produce only vegetative shoots; and, of course, the number of such buds may be much smaller than the number removed in pruning. It seems possible that the amount of cutting-back usually done (generally more than half the length of the branch) should tend to reduce the yield perhaps to a considerable extent in years

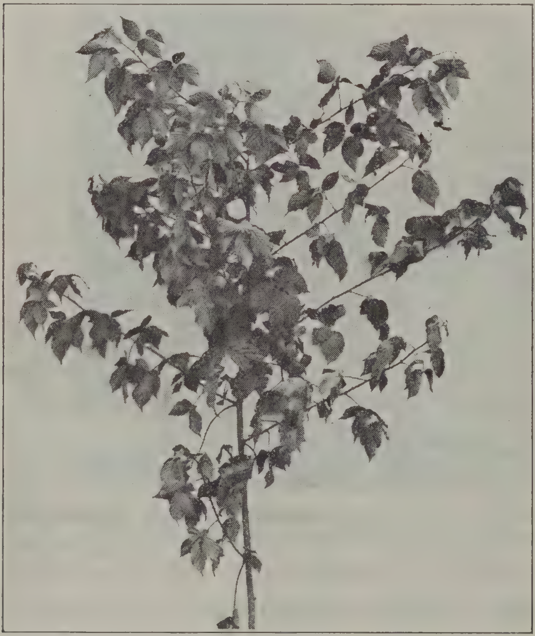

Figure 41. Blackberry shoot showing nature of growth of upright varieties when shoots are pinched at about two feet in height, thus causing low branching.

when the water supply is satisfactory; but in dry years canes so pruned ripen their fruit better than do unpruned canes. It is well known, also, that severe cutting-back of the canes may enable plants badly infected with orange rust to ripen their fruit, when, without the pruning, only the earlier fruits would ripen satisfactorily, the others drying up In spite of these evident benefits from pruning under abnormal conditions, we need the results of experimental work as to the extent of reduction of yield, if there is any, following pruning when weather conditions are favorable for a maximum yield. Of course, it is well known that the canes of most species of blackberries and the canes of raspberries fruit only during one year, and they must then be removed. It is often recommended that this removal be done as soon as the fruiting season is over. Whether or not there is any measurable benefit from such early removal as compared with removal at any time during the dormant season, we have no experimental evidence. It would seem probable that in sections where the growing season is long such early removal of the old canes might reduce the total transpiration from the row and thus increase the water supply for the new shoots, though as to whether or not the amount of water thus saved would ever be great enough appreciably to influence the yield we have no data; neither have we data as to whether or not, in sections with an abundant water supply, leaving the old canes with their leaf surface would measurably increase the amount of organic food going into the roots.

In the Pacific Coast section of America, Loganberries and related kinds are practically always trained on trellises. Occasionally a single wire trellis is used, but generally there are two or three wires. According to Darrow (803) there are used what is called the weaving system, by which at the end of the growing season the new canes are each woven separately on the wires, and the rope system, by which the canes are wrapped around the wires in bundles; if there are two wires there may be four bundles of canes, one bundle running in each direction on each wire. It would seem that by the weaving system the yield should be larger since by weaving the canes across from wire to wire much more leaf surface should be exposed to the light than could be exposed when all the leaf surface and fruiting clusters must start from close around the wires. However, I know of no experimental results as to the comparative yields by the two systems. Further, the largest yield to the acre may not be associated with the largest profit to the man, particularly with crops requiring so much labor.

The new shoots are left to run on the ground along the rows until the fruit is harvested and the old canes are removed. In sections where there is danger of winter killing, they are left on the ground until the following spring, but in other sections they are trained up soon after the old canes are removed, when they are less brittle and are therefore more conveniently managed than at the end of the growing season.

The Himalaya blackberry bears fruit of excellent quality but is not grown extensively except for home use or local market, because it grows so luxuriantly, forming such a thick mass of canes that the fruit is picked with great difficulty and the vines spread so rapidly that they become a nuisance. The older parts of the canes live for a number of years and Professor Bioletti tells me that in his home grounds he is able to facilitate the picking of the fruit, and to reduce the expense of removing extra suckers and preventing spreading, by training one or two canes each way from the central portion, these canes being used as arms as in the cordon system for grapes. Of course, the other suckers are pulled out and the branches from these arms are cut back to spurs each year or oftener; and from these spurs grow the fruiting wood. If it becomes necessary to cut off one of the old arms a new one is obtained by permitting a sucker from the base to grow. Arms are known to have remained in a healthy condition at least five years. Some growers renew to new canes every year, tying several each way on wire trellises and removing all suckers except enough for the next year's canes. Some meager experience suggests that the yield of plantings so trained is but slightly if any greater than with the cordon system, and the labor of pruning and harvesting is much greater. With either system the plants should be eight feet apart each way or more, depending on soil conditions.

The strawberry. The habit of the strawberry plant of renewing by runners is well known. The most common method of training is for the runners to be straightened into a row by the cultivation, and for a matted row thus to be formed, this row varying in width with the variety, soil, and method of cultivation. This is certainly the cheapest method of training the strawberry. Usually the rows are at least eighteen inches wide; and with strong plant-making varieties sometimes the runners are cut in order to prevent the plants from becoming too thick. It is generally observed at picking time that the best fruiting plants are those near the edges of the row. Some growers, therefore, put their rows closer together and keep them narrower, either by putting the plants further apart in the row or by cutting some of the runners. Occasionally what is known as the single or double hedgerow is used. By the single hedgerow only two runners are permitted to form from each plant, one in each direction along the row. By the double hedgerow four runners, two in each direction, are permitted to form. Of course, by such systems the rows are placed as close together as it is possible to have them if a horse-drawn cultivator is used. Naturally after the plants have filled these narrow rows, the runners must be cut. When the runners are cut from a plant having plenty of room, new crowns bearing buds are formed around the original crown. And if the runners are kept cut throughout the summer, a plant may become a mass of crowns sometimes a foot or more in diameter. It seems that, here, there is an interesting manifestation of polarity. The runner inhibits crown formation on the original plant even after there has been rooting at the nodes. In other words, the inhibiting influence of a growing runner seems to be transmitted even through one or even several rooted nodal plants, crown formation at these nodes being also inhibited. Generally only a small number of crowns form on any plants unless the runners are cut. In fact even when a wide matted row is used it seems wise to cut the runners, after the row becomes fairly thick, and thus to encourage the formation of extra crowns on the plants that have rooted. Further, when the runners are kept cut and new plants prevented from forming, there is avoided the crowding of earlier formed, more fruitful plants by later formed, less fruitful ones; for Davis (805) found that in Canada the early formed plants are the more fruitful even when all are given plenty of room. In fact, the earlier formed plants seemed to be the better ones to take for planting new beds.

When all the runners are cut from the plants from the time they are set the form of training is known as the hill system, the advantages of which are that the planting is more easily kept free from weeds, the berries stand up better out of the mud and, it seems, are larger, and, particularly, that the fruit continues to be of good size towards the end of the picking season. Where the rows are placed far enough apart to be cultivated with a horse, unquestionably the yield to the acre is reduced. This would not be a determining factor if an acre could be grown more cheaply; but experience seems to indicate that the labor of cutting the runners is so great that the cost of growing an acre is probably increased. The same seems to be true of the hedgerow system. At least a very large majority of growers train to a rather wide matted row system. In a home planting, that is cultivated entirely with a hoe, and where the labor of cutting runners would not be an important item, unquestionably the hill system would give the greatest satisfaction, since without horse cultivation the rows could be closer, the yield would probably be greater, and the berries would certainly be better.

We can hardly be certain as to the best practice of renewing the beds, or whether or not they should be renewed after the first crop. This is particularly true with the matted row system. Some growers harvest but one crop and plough up the bed. This is very expensive, since there is the cost of the plants and of labor for planting and care for every crop obtained, and generally two years' use of the land for one crop. Other growers harvest three or even more crops before ploughing up the bed. In fact, Brown (579) reports profitable results in Oregon from keeping the planting until six crops had been harvested. A single plant may live a number of years, the old root system dying each year and new roots growing from the new crown at the top of the plant. Perhaps because of this change in the root system each year the plants seem to become weaker and smaller; and, in renewing a bed, it is generally the custom, where the matted row is used, to plough away a part of each row, leaving only a narrow strip from which the new plants will grow. There are sections, however, where the growing seasons are so short that after the renewal (which must be after the picking) not enough fruiting plants will form to give a good yield in the succeeding year. Under such conditions, it would be better to leave the old row even though plants did not fruit so well after bearing the first crop. As to about how much the decline in fruiting of a plant with each succeeding crop may be, we need the results of careful study through a number of years with varieties whose plants tend to be vigorous and varieties whose plants tend to be weak, growing under climatic and soil conditions that tend to cause rapid decline and under conditions that favor long life. With such data it should be possible, in any given section, more wisely to decide whether it would be better to let the planting fruit only one year, to renew it each year by cutting away most of the old plants and growing a new row from those left, or to leave the same old plants to fruit for two or more years. Such a study would be very difficult to make, however, because decline in vigor of the plants after fruiting is not the only way by which the yield in succeeding years would be reduced. Plants might be killed or weakened by insects, by freezing, and by other means.

CHAPTER 20

SOME RESPONSES OF FRUIT TREES TO CLIMATIC DIFFERENCES

Experimental results obtained with trees in one section, or the results of practical experience, cannot be applied in another unless it is known how greatly the climatic differences involved may influence such results. It is evident that the study of such influences is very complicated, so many environmental features being involved that it is not always possible to learn which is the most important in determining the gross response of the plant. For example, it is not always certain whether the difference between the behavior of a variety in high latitudes and that in low latitudes is due to the difference in the length of daily illumination, the summer temperature, the winter temperature, the length of the growing period, the length of the dormant period, or to something else. The response of the tree to differences in the water supply has been discussed in earlier chapters. It seems best here to limit the discussion mainly to climatic differences found at different distances from the equator.

The relative length of day and night. The length of daily illumination is shorter in summer and longer in winter at lower than at higher latitudes. Garner and Allard (999) found very striking results to follow varying the length of this daily period of illumination. With some of the plants studied there was flowering and fruiting only when the length of day fell within certain limits. Some species and varieties flowered only during rather long days, others only during rather short days, and others were not influenced by the length of day. They varied the daily period of illumination by placing the potted plants in dark chambers during parts of the day; for a seven-hour exposure to light the plants were generally placed in the dark chamber at 4 P.M. and returned to the light at 9 A.M. In winter the length of day was extended by use of electric lights. Oakley and Westover (1098) found that the different varieties of alfalfa could be readily identified by the difference in response to a length of daylight shorter than that of midsummer at Washington, D.C. Schaffner (1134) found with hemp that plants grown in the greenhouse during short winter days in Ohio came into bloom in twenty to thirty days from the time of planting, while those planted in May and growing during the long summer days required forty days to come into bloom. The plants were also shorter lived when grown during the period of short winter days; but, if still alive, would tend to be rejuvenated by the longer days of spring. Even the sex of the plants seemed to be changed by the shorter daily exposure in light. Harvey (1024), however, grew from seed to maturity in continuous artificial light, many plants, including wheat, oats, barley, rye, flax, buckwheat, white sweet clover, peas, beans, lettuce, and a number of common weeds, all of these blooming and forming good seed. Potatoes, tomatoes, red clover, alsike clover, squash and Silene bloomed but did not form seed; though the potatoes produced tubers of good size.

Adams (924) found with wheat, Indian corn, liver leaf, white mustard, wax bean, flax, coolwort, sunflower, and dandelion, that reducing the length of daily illumination below that in summer at latitude 45.5 degrees reduced growth and tended to delay blooming; with soy beans and tomatoes the results were not conclusive. And Garner and Allard found with all the species that they studied that the rate of growth was in direct proportion to the length of daily exposure to light. This seems in agreement with the work of Rivera (291), who found the accumulation of carbohydrates to be in proportion to the number of hours the plant is exposed to the sunlight and not in proportion to the intensity of light. This would be expected, if in daylight the limiting feature as to photosynthesis were the supply of carbon dioxide.

Klebs (1047) found that *Sempervivum*, which in the north temperate zone usually flowers during the long days of June, was caused to flower in mid-winter when the length of daily illumination was extended by means of electric lights. He thinks that this increase in the daily amount of light received by the plant causes flower formation by increasing the concentration of carbohydrates in the tissue. Nightingale (252) seemed to find, with tomatoes in reference to flowering, some relation between the influence of the length of daylight and the influence of the carbohydrate-nitrogen relationship; though with salvia, buckwheat, soy beans, and radishes the relationship was not very clearly marked.

Nearly all the work concerning the effect of varying the length of daily illumination has been done with herbaceaous plants. Garner and Allard (1000) reduced to twelve hours the length of daily illumination in summer with a few apple trees. They seemed to find that growth is checked in midsummer by the very great length of daily illumination. With trees exposed to full daylight, growth seemed to be better before and after the period of longest days. However, the conditions of the experiment were such that only one out of three grafts planted and exposed to full length of day lived. Certainly an experiment done under such conditions can give no dependable information. Young apple trees in the nursery and older trees pruned severely grow during the midsummer months of high latitudes with the long daily illumination; and Macoun (1069) says that in Canada at latitude 56° apple trees continue growth through the very long summer days. Conclusive information as to whether or not the rate of growth is reduced by long daily illumination can be obtained only by means of very careful experimentation with considerable numbers of trees. Phillips (1109) did not find the terminal buds forming earlier in high latitudes than in lower latitudes; but other influences than length of daylight would cause length growth to cease. Garner and Allard suggest that the long midsummer periods of daylight in high latitudes are unfavorable for growth but favorable for fruit-bud formation, and that as the tropics are approached the shorter length of summer days favors vegetative activity at the expense of flower-bud formation. In latitudes below about 31° to 33°, the apple is generally not highly fruitful. As to whether or not length of daylight is an important cause of this condition, I do not know of any evidence. We know, however, that in apple-growing sections, the differentiation of fruit buds may begin in autumn when the length of day is approximately that of the tropics. Magness (231) found flower parts in some spur buds of the apple by July 9th in Oregon, and the raised crown that is evidence of the initial stage of fruit-bud formation was sometimes present by June 14th. Yet with the same varieties the youngest stages of flower formation were sometimes found as late as September 8th. With these varieties, then, there is a period of three months or more during which there may be fruit-bud differentiation. This begins when the days are longest and continues until the days and nights are equal. In other words, it suggests that in going from Oregon to the tropics there would not be encountered a length of summer day that with these varieties would prevent the formation of fruit buds. However, it is possible that the longer days before September had caused the development of chemical conditions in the wood favorable to fruit-bud formation, and that if the length of day throughout the summer had been that of September there would have been little or no fruit-bud differentiation. With temperate zone fruits it may be that in the higher latitudes, such as those of New York or parts of Canada, the longer days are more favorable for fruit-bud formation than are the shorter summer days of fruit-growing sections in lower latitudes such as Arkansas, North Georgia, Southern California, and Arizona; we can only say that other influences such as the soil nitrogen supply are of so much greater importance that any influence of the length of daily illumination is not easily to be determined. And in these locations nearly all temperate zone fruits are to be found reasonably productive. In fact, Dr. L. H. MacDaniels informs me that at Mexico City, within the torrid zone, he has seen peach and plum trees fruiting well and apple and pear trees at least reasonably well. And Mr. Alvero Rebolledo, consul from Colombia, says that in his country, apples, pears, and peaches fruit well at suitable elevation but three degrees from the Equator. Either summer or winter temperatures must be important as influencing fruitfulness (fruit-bud formation or fruit setting); for, in the lowest latitudes at which temperate zone fruits are grown fruitfulness seems to be better at the higher elevations. Thus, at Mexico City the altitude is 7400 feet; and in Colombia apples and pears seem to fruit best at about that elevation, though peaches are said to fruit well at altitudes as low as 3500 feet.

Influences that favor the differentiation of fruit buds may not necessarily determine the opening of the flowers. Garner and Allard (1000) seem to think that the shortening daylight following midsummer, by favoring vegetative activity, may delay the process of differentiation of flower parts and thus prevent blooming until the weather is too cold. However, there is generally very little vegetative activity after midsummer, and even after the leaves are off, the weather is often warmer than that which brings the trees into bloom in spring, after they have ended their rest periods. We can be reasonably certain that length of day has little to do with the time of blooming except as it may influence the going into and the coming out of the rest period. (Garner and Allard seemed to find that, with some plants at least, the rest period is influenced by the length of daily illumination.) For if the buds have been exposed to a sufficient period of chilling or other treatment that breaks the rest period they will open during the period of shortest daylight, in December or January, and, if retarded by low temperature, they will readily open in June when the length of daylight is greatest. The opening of the flowers in late summer or autumn is prevented by the rest period. If this is broken by a condition of severe drought or other disturbing influence, the blossom buds may open in autumn or even in midsummer.

Length of the annual period warm enough for growth. When altitude and ocean influences are not involved there are at lower latitudes more days in which the temperature is high enough for growth. In so far as photosynthesis is concerned this is partly compensated for by the greater length of daily illumination at higher latitudes. Young trees, during one or two years in the nursery tend to make considerably larger growth at latitudes 35° to 40° than is made at higher latitudes. The same tends to be true of trees during the first four or five years in the orchard; but it is not certain that annual growth continues to be greater at lower latitudes after the trees are ten or fifteen years old. Casual observations suggest that in the eastern part of the United States the reverse may be true. In the northeastern part of the United States — Michigan, New York, and New England — with the apple and with some other fruits mature trees seem to be more vigorous and trees seem to live longer than in lower latitudes of the eastern part of the country. However, other features such as soil conditions, prevalence of such diseases as blister canker, and heaviness of fruiting so complicate the problem that it is not certain that any observed difference in vigor is due to difference in climate alone.

Phillips (1109) found that the terminal buds are formed as early or a little earlier at lower latitudes than at higher ones. There would thus be a much longer period warm enough for growth after length growth had ceased at low than at high latitudes. Several times in previous chapters there has been suggested the possibility that if photosynthesis continue long after top growth had ceased, there might be an injurious accumulation of products, such as gums, that might interfere with the most rapid conduction of water. Thus, it has been suggested that in the eastern half of the United States, the trees need renewal pruning younger at lower than at higher latitudes. We have no strong evidence that there is such a condition resulting from difference in climate; and, even if there were, it might be due to difference in winter or summer temperatures, or to differences in the length of the winters rather than to differences in the length of the growing seasons.

The length of the growing season should affect the fruitfulness, at least of young trees, since with long summers there will be a longer time in which fruit-bud formation may take place; however, the greater length of midsummer day at higher latitudes might, in its influence on fruit-bud formation, offset or more than offset the greater length of growing season at lower latitudes. There are little or no data as to the bearing age of the different fruits in lower and higher latitudes. Such data would be of little value unless the same varieties were involved, and unless the amount of pruning in the different sections were about equal. Casual observation indicates that with most fruits that do well at the lower latitudes, the trees begin to bear younger than at higher latitudes. The difference is not so great, however, as earlier experience in North America has suggested. Thus, apple orchards of New York have a record for coming into bearing much later than do those in fruit sections farther south. The difference, however, has been due largely to the fact that the trees in New York until recently were trained to high heads. When the young trees at the higher and at lower latitudes are pruned but little, the difference in time of coming into bearing is not great.

The length of growing season may affect the quality of the fruit. In lower latitudes varieties requiring a very long season might ripen better. Some varieties of apples ripen enough earlier in lower latitudes to bring the ripening process into rather hot weather. With some varieties this would result in lower quality, while with others a higher quality might result.

Length of the period too cold for growth. We have seen in Chapter 3 that any deciduous fruit plant has a rest period, a period when even though temperature and moisture conditions may be favorable, growth will not take place. There may be slowly continued development of the flower parts in the flower buds, but neither the flower buds nor the leaf buds will open. This period generally ends some time during the winter months, not suddenly, but gradually; trees grow at a given temperature more rapidly in February than in January and more rapidly in March than in February. A period during which the temperature is rather low is necessary to bring the buds of most deciduous fruits out of the rest. It is not necessary that the temperature be below freezing or even too low for the growth of some plants. In parts of California roses and many other plants may be blooming and Citrus and other fruits growing and ripening during the rest period of deciduous fruit trees. However, during the three or four coolest months the growth is very slow; it may be two months or longer after a rosebud shows before the rose is fully open.

It seems probable that in lower latitudes where freezing or even chilling weather does not begin until late or where there are many days in winter when freezing or chilling temperatures do not prevail, the trees will not be so nearly through their rest periods when growing spring weather begins but that the initial growth or the pushing into bloom will be slow. Any one who has had an opportunity to observe the starting of trees at both high and low latitudes knows that the initial spring growth is much more vigorous at higher latitudes. Growth is retarded by the rest period even more than is blooming. In Figure 42 is shown the amount of leaf growth when the flower parts are dropping from the small Elberta peaches at Experiment, Georgia, north latitude 33°; and at Geneva, New York, north latitude 43°. The leaf growth relative to blossom and fruit development has been much the more rapid at the higher latitude.

At the lower latitudes at which the common deciduous fruits are found, growth or blooming may not begin earlier than in somewhat higher latitudes. Thus, I have observed the blooming of Elberta and other peach varieties to be slightly later at Morrill, Texas, latitude 31° 5′, than at points in South Missouri, latitude 37°. Yet the altitude is the greater in South Missouri. The winter in South Texas had been a very warm one;

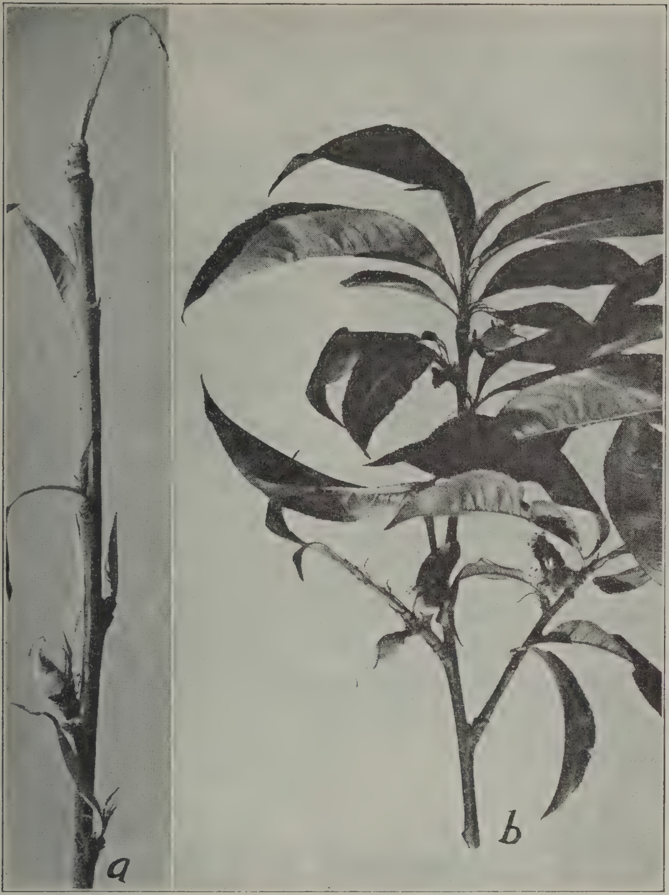

FIGURE 42. Showing leaf development when flowers have just fallen, *a*, at Experiment, Georgia, latitude 33, and, *b*, at Geneva, New York, latitude 43.

and evidently by the end of March the trees were not far enough through their rest period but that their initial response to growing temperature was very feeble. After the first leaves were formed, however, growth proceeded more rapidly. Mr. C. F. Kinman tells me that at Yuma, Arizona, latitude 32.7°, he has observed peach trees with which the blossoms were not open until May, although the midwinter temperature was probably warm enough for growth. Evidently the rest period had greatly delayed the opening of the buds.

Phillips (1109) gives the average blooming dates through a period of ten years for points at different latitudes in the United States. Figures 43–45 show graphically the date of full bloom of some common fruits at the different latitudes along the Atlantic Coast and in the Mississippi Valley, and in the Pacific Coast section.

These graphs show the estimated blooming date at sea level; correction for altitude having been made by deducting from the actual blooming date of a given section one day for each one hundred feet above sea level in accordance with the work of Hopkins (1034). With the large number of records studied by Phillips the average delay in blooming was one day for each one hundred and one feet of elevation. Even after this correction is made the irregularities do not disappear from the graphs. Differences in the amount of cloudiness and the influences of large bodies of water are also involved. It is interesting to note that with the Ben Davis apple in the Mississippi Valley the average blooming dates during a period of ten years are the same at latitudes 32° and 38°. Yet between the blooming dates of latitudes 38° and 44° there is a difference of about thirty-one days. The peach shows about the same blooming time at latitudes 32° and 36°, and the Abundance plum at latitudes 31° and 33°. Probably the trees of kinds such as the apple and the peach, when growing at latitudes below 36° to 38°, are not completely through the rest period when the spring weather becomes warm enough for growth; and so the growth response to a given temperature is less rapid than at latitudes above 38°.

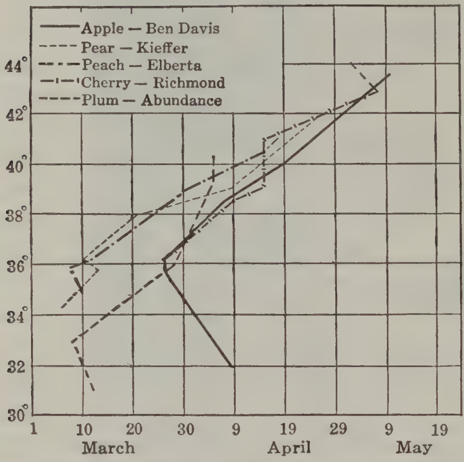

Figure 43. Mississippi Valley Section. Dates of full bloom for different latitudes, corrected for altitude, average for ten years, 1902–11. (After Phillips.)

In the Pacific Coast region, the delay in blooming for a degree of latitude is generally less than in the Atlantic Coast region or in the Mississippi Valley; and the influence of the rest period is less clearly marked; though, except with the apple, the delay in blooming for a degree of latitude is considerably greater above than below latitude 40°. The winter and spring temperatures in the different sections of California are differently modified by ocean and mountain influence; and the length of the period cold enough to be favorable for ending of the rest period does not increase with higher latitude in the rather uniform way that characterizes the Mississippi Valley. Observation indicates that, at least as far north as latitude 40° or farther, in the warmer locations the winters are too warm for the complete ending of the rest period; and the response of fruit buds and wood buds to spring weather warm enough for growth is less rapid than it would be if the rest period were fully ended. In some years in California spring blooming of kinds such as the peach and the pear is later in the southern part, where the winters are very warm, than in the northern part with its cooler winters. In the summer of 1924, following a warm dry winter, peach trees, pear trees, and trees of some other kinds were not in bloom or in leaf until about June 1. Yet, later in the summer, they made a normal growth, though few of the blossoms that finally opened set fruit.

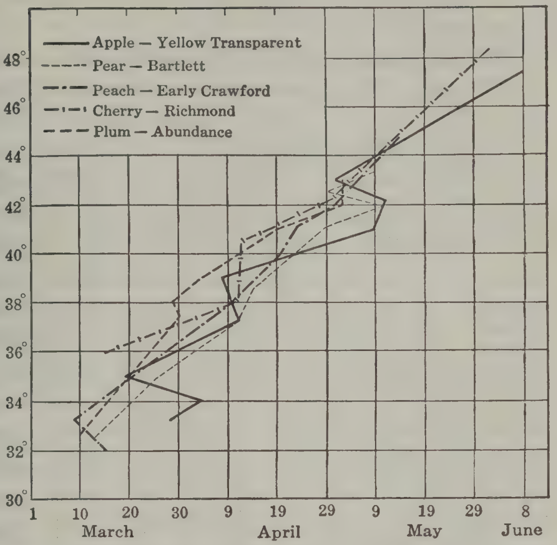

FIGURE 44. Atlantic Coast Section. Dates of full bloom for different latitudes, corrected for altitude, average for ten years, 1902–11. (After Phillips.)

In the Atlantic Coast section also, the influence of the rest period on the time of blooming at the lower latitudes is not as marked as in the Mississippi Valley. However, since the average delay in blooming for a degree of latitude is less above than below latitude 36° to 38°, it seems probable that at the lower latitudes blooming is delayed slightly by the conditions of partial rest when warm spring weather begins. Ocean winds probably influence the temperature differently at different stations along the Atlantic Coast. Further, it was suggested in Chapter 3 that the ending of the rest period may be brought about more rapidly by temperatures continuously too cold for growth, but above the freezing point, than under conditions where there is fluctuation from severe freezing temperatures to temperatures high enough for growth. The influence of the ocean would tend to be toward the former type of winter; and, at lower latitudes in coastal regions than in inland regions, the rest period may be fully ended before there is spring weather warm enough for growth.

With the peach tree, and probably with other kinds, any treatment that increases the vigor of growth of the tree tends to delay the ending of its rest period in the following winter (966, 967). And at latitudes as low as 37° in Missouri, peach trees that, by means of pruning or fertilization with nitrogen, have been caused to grow vigorously in the previous summer, will, in nearly every spring, bloom a little later than peach trees of low vigor. At Columbia, Missouri, latitude 39°, however, during twelve years of observation, there was never a year when the more vigorous trees bloomed the later. At that latitude in the Mississippi Valley, the rest period seems to be completely ended by the time the weather is warm enough for growth. And McCue (666, 667) did not find very vigorous trees blooming later than trees of low vigor in Delaware at latitude about 39°. It is probable that, for the reason mentioned in the previous paragraph, at considerably lower latitudes along the Atlantic Coast the rest period will be completely ended before growing spring weather prevails. However, Professor J. A. Bizzell tells me that at his farm in North Carolina at a latitude of about 35° and an elevation of about one hundred and fifty feet, Greensboro peach trees, heavily fertilized with nitrogen in one spring, were delayed a week in blooming in the next spring. The trees were in a sandy coastal plain soil in which an application of nitrogen caused a vigorous growth that continued considerably later in summer than did the growth of unfertilized trees. It seems that along the At-

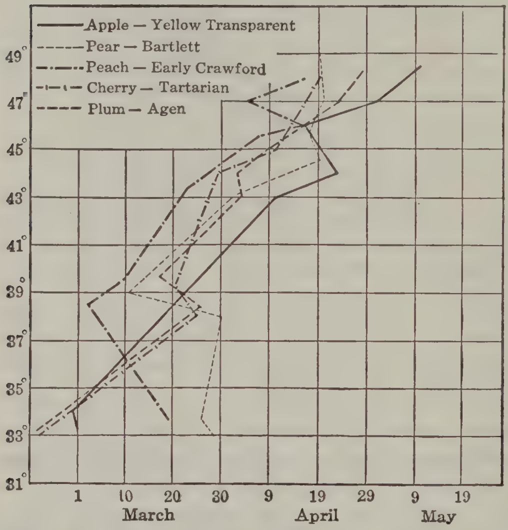

FIGURE 45. Pacific Coast Section. Dates of full bloom for different latitudes, corrected for altitude, average for ten years, 1902–11. (After Phillips.)

lantic Coast, at low altitudes, as far north as latitude 35° the blooming time of peach trees is influenced by the degree to which they have emerged from the rest period when growing weather begins; but that the influence of the rest period on blooming time does not extend much north of latitude 35°. At higher elevations it probably would not extend that far north.

In the Mississippi Valley the difference between the time of blooming of the earliest and the latest blooming fruits is very much greater at lower than at higher latitudes. This difference is much the greater in the region below latitude 36° to 38°, where the rest period seems to delay the blooming. This suggests that the great difference between the blooming dates of different fruits at lower latitudes may be due to the fact that when temperatures favorable for growth begin to prevail some of the fruits are more nearly completely out of their rest period than are others. Whether or not the pear has a particularly long rest period is not known from experimental evidence, but its blooming in high and low latitudes suggests that its rest may be long. Thus at Geneva or Ithaca, New York, in most years, it blooms slightly earlier than the peach, while in California at latitude 33.7° the ten-year average blooming date of the Bartlett pear was March 27th, while that for the Crawford Early peach was March 21st (Phillips, 1109). McClatchie and Coit (1076) say that in Arizona the pear is one of the latest blooming fruits. The conclusion that all the greater difference, at lower latitudes, between the blooming times of different fruits is due to differences in the length of the rest periods of these fruits may not be warranted; for even at latitudes 38° to 40°, where with all fruits the rest period seems always to be ended before there is spring weather favorable for growth, the difference between the blooming times of different fruits is wider than at latitude 42° to 44°. It may be that at the higher latitudes the increase in daily mean temperature in spring is more rapid than at lower latitudes. If this were true it would be expected that the different fruits would bloom more nearly together, for the additional number of heat units required to bring the later forms into bloom would be accumulated in fewer days. It is well known that, in most sections, during springs when the temperature is considerably above the normal, the different fruits are in bloom at more nearly the same time.

Responses to Heat

Heat required to bring trees into bloom. A large amount of early literature concerning the influences which determine the time of opening of the fruit buds and leaf buds in spring — and concerning other stages in the annual development of plants — has been reviewed by Waugh (1157) and Abbe (923). It does not seem necessary to discuss all of that literature. There was early developed a doctrine of thermal constants (called also physiological constants) by which it was assumed that a given stage in the development of a plant is reached when the plant has received a certain amount of heat. By some, the number of degrees above the freezing point was used and by others, the number of degrees above a temperature thought to be high enough for growth. De Candolle (983) seemed to find experimentally that at the temperature of 43° F., a large number of plants or plant parts will begin to grow; though he emphasized the fact that different plants and even different parts of the same plant, such as the flower buds and leaf buds, may begin to grow at different temperatures. The mean daily temperature was used; the assumption being, that when days enough were involved, the amount of heat received in a day would be indicated with a fair degree of accuracy by the mean temperature. An arbitrary starting-point was often January 1st. The physiological constant was calculated by comparing the mean temperature of each day between the starting day and the blooming date, with the basal temperature (32° or 43° F. or some other temperature). For some days the mean temperature would be lower than the basal temperature. Such days would be ignored; and there were added together for all the other days the numbers of degrees by which the mean temperatures exceeded the basal temperature. Waugh (1157), Sandsten (1133), and others found in different years even for the same variety in the same location no dependable relation between such sums and blooming dates.

Loeb (1055), Price (1116), Livingstone and Livingstone (1054), and others have called attention to the fact that growth is in a large measure chemical action and should be expected to proceed partly in accord with the principle of Van't Hoff and Arrhenius that the velocity of chemical action doubles, or a little more than doubles, for each rise in temperature of 10° C. Livingstone and Livingstone devised what they called an efficiency summation by which allowance was made for the more rapid growth at the higher temperatures. They found, however, that by using the old direct summation method of the phenologists most of the area of the United States would be placed in the same climatic zones as when the efficiency summation was used. Livingstone (1053) later proposed a formula by which allowance was made both for the more rapid growth with increasing temperatures up to the optimum and for the slower growth made at temperatures above the optimum. With American wild plums Waugh found the following summations of mean daily temperatures above 32° F. from January 1, to blooming; at Stillwater, Oklahoma, 967° F.; at Parry, New Jersey, 909° F.; at State College, Pennsylvania, 725° F.; and at Burlington, Vermont, 577° F. Bradford (954) showed that for the late Crawford peach the summation of temperatures above 43° F. from January 1st to blooming time was more than twice as great at Pomona, California, as at Wauseon, Ohio. The rest period must have delayed response to growing temperatures at Pomona, California, and may have done so at Stillwater, Oklahoma, but it is doubtful if it could have been important at as high latitudes as State College, Pennsylvania or even at Parry, New Jersey. From the study of Loeb, the Livingstones and others, we should expect the temperature sum ("physiological constant") that would bring the trees into bloom to be smaller the more nearly the average daily mean approached the optimum for growth. That is, if in the time from the basal day (perhaps January 1st) to blooming there were a large number of days only a few degrees above the basal temperature, the so-called physiological constant would be large; for the response to such temperatures would be slight. At higher latitudes such as that of Burlington, Vermont, the daily exposure to sunlight is greater than at lower latitudes when spring days begin to have a mean temperature as high as 43° F.; and there are fewer days with a mean temperature only a few degrees above 43° F., before the beginning of weather warm enough for rapid growth. This principle probably accounts for most of the difference between the "physiological constant" at Burlington and that at State College or at Parry; and for some of the difference between that at Burlington and that at Stillwater or even at Pomona.

According to Abbe (923), Alexander von Humboldt early insisted upon the necessity of taking into consideration sunlight itself in studying the influences that bring on annual stages in plant development. Whitten (1165) and others have shown that before the leaves are out, the twigs in clear sunlight, through the absorption of heat by their pigments, maintain a temperature well above that of the air; twigs with the most dark pigment absorbing the most heat. Buds on whitewashed peach twigs were appreciably delayed in blooming. This suggests that the daily mean temperature of the air may not be trustworthy as indicating the amount of heat to which the tissue itself has been exposed. We should not necessarily conclude from this that in a section where there is much sunshine more growth should be expected from a given mean daily temperature than in another where the mean is the same but the sunlight less intense. Much may depend upon the extremes from which the mean is secured. On a clear sunny day when the temperature of the twigs may be well above that of the air, the difference between the maximum and minimum may be considerably greater than on cloudy or hazy days. Thus, let us say, that in any place it is cloudy and the mean temperature is 55° F., the maximum being 60° and the minimum 50° F.; while in another place the mean is 55° with a maximum of 75° and a minimum of 35° F. In the latter case the twigs would be at a temperature above that of the air during a part of the day, but the temperature would be too low for appreciable growth during the night. In the former case the twig temperature would not be so high during the day but the temperature would be high enough for some growth throughout the night. It is not possible to say with which the amount of daily growth would be greatest. There might be little difference. If, however, the mean should be 30°, with the maximum 35° and the minimum 25° F., with the weather cloudy or hazy, there would be little or no growth, while if the sunlight were intense and the mean were 30°, with the maximum 40° and the minimum 20° F., the temperature of the twigs might be ten or fifteen degrees above 40° F. during part of the day, and there might be growth. The fact, however, that the higher night temperature of the cloudy day may at least partially compensate for the heat absorbed by the twigs on the sunny days suggests that the mean temperature may be a rather accurate guide as to the amount of growth to be expected.

The temperature favorable for spring growth would, of course, not be the same for all fruits, and for this reason the order of blooming might not be the same every year. Thus, in New York the pear is generally in full bloom about a day before the peach, but in some years the peach blooms first. This would be explained if it were known that the pear will grow more rapidly at a rather low temperature than will the peach. Then if the temperature during the period in which the blossoms were opening should be below that most favorable for rapid development of the peach buds, the pear buds would open first; but, if it were very favorable for the growth of both, the peaches would open first, because less growth is necessary in the opening of the peach. Waugh (1158) suggests that even different parts of the same flower may respond differently to some temperatures; with some kinds the pistils reaching maturity first in some years and the stamens first in others. Hedrick (1028) says that according to his observations with blossoms of apples and pears the stamens grow more rapidly than the pistils during exceptionally warm spring weather and less rapidly than the pistils during cool weather.

Hopkins (1034) has prepared maps on which isoplanes indicate zones of approximately equal times of occurrence of periodic activities of plants and some animals in North America. He finds that except for special local influences these activities are delayed about four days for each degree of latitude, for each five degrees of longitude eastward, and for each four hundred feet of altitude. We have seen that, probably on account of the rest period, this delay due to latitude is not uniform, in so far as the blooming time of fruit trees is concerned; there being little delay in blooming of some fruits between latitude 31° and latitude 38°

As to longitude, also, the blooming time of fruit trees does not agree with the map prepared by Hopkins. According to his map the blooming date at latitude 33° on the Atlantic Coast should be about the same as at latitude 42° on the Pacific Coast; yet Phillips (1109) found the blooming date of the peach about the same at latitude 33° on the Atlantic and the Pacific Coasts. At that latitude the pear blooms later on the Pacific than on the Atlantic Coast, though the apple blooms slightly earlier on the Pacific Coast. And with the pear below latitude 36° to 38°, the blooming is not appreciably if at all earlier in the Mississippi Valley than on the Atlantic Coast. Above that latitude the blooming in the Mississippi Valley is earlier, and on the Pacific Coast considerably earlier, than for corresponding latitudes on the Atlantic Coast.

Briefly to summarize, the amount of heat (above the minimum growing temperature) received by the plant is very important as to its blooming time; but the temperatures of plants during the day are determined not alone by air temperatures, but also by the amount of direct sunlight received by the twig; and by the velocity of the wind during sunny weather, high winds tending to lower the difference between the temperature of the twig and that of the air. And the amount of heat required to bring the tree into bloom will be smaller the nearer the daily temperature is to the optimum for growth. At latitudes below 36° to 38° in the Mississippi Valley, latitudes near that in Atlantic Coast sections, and at still higher latitudes in Pacific Coast sections, the amount of heat required to bring the tree into bloom is greater with some kinds because the trees are not through the rest period when the warm weather begins. Determinations of the "physiological constants" for the blooming of a given fruit at the same location, but in different years or at different locations in the same year, may be of service to ecologists or geographers in determining broad zones in which certain fruits may grow, but it is of little or no service to the pomologist who, in studying orchard practices, may wish to predict the blooming date to within a few days. Records of blooming dates in previous years, of the same varieties in the section concerned, would be much more valuable in predicting blooming dates for any succeeding year than would be records of temperature accumulations by given dates. Relatively few days of high temperature immediately preceding blooming are of much more importance in determining the blooming date than a much larger accumulation of temperatures a little above the minimum for growth.

Heat required to bring fruits to ripening. It is probable that the sum of the daily mean temperatures is more nearly the exclusive agency in determining the ripening date than in determining the blooming date. Thus, in the year mentioned when Elberta peach trees were observed to bloom slightly later in South Texas at latitude 31° than in South Missouri at latitude 37°, the fruit was ripe approximately one month earlier in Texas than in Missouri. In other words, the time from blooming to ripening was about one month shorter in Texas than in Missouri. According to Phillips (1109), with the Elberta peach in the Mississippi Valley, the average number of days between full bloom and ripening during ten years was one hundred and fifteen at latitude 31.5°, while at latitude 37° it was one hundred and thirty. In other words, at the lower latitudes the rest period delays the blooming, but there is no corresponding delay in ripening. Phillips found that, in the Mississippi Valley, after correcting for altitude, there was between latitudes 31° and 41°, a delay in ripening of Elberta peaches of 5.8 days for each degree of latitude; with the Ben Davis apple between latitudes 32° and 43.5°, the delay for each degree of latitude of 4.7 days; and with the Abundance plum, the delay was about 4.4 days. The curve for the Atlantic Coast section was very similar to that for the Mississippi Valley section.

It would be expected that the ripening of the different fruits would not be affected equally by differences in temperature. There are a few striking examples of a greater effect of the heat on the ripening date of one fruit than on that of another. The blooming date of the Ben Davis apple in Central Missouri is about April 13th, and in southern New York about one month later; the picking date in Central Missouri is about October 20th, and in southern New York about October 28th. We have no data concerning the blooming date of grapes in Missouri, but from observation I am certain that it cannot be more than two weeks earlier than in southern New York; yet Concord grapes would be picked about August 20th, in Central Missouri, and in October in New York. It is probable that the Ben Davis apple is in a more completely ripened state when picked in Missouri than in New York; but, after making allowance for that, it still seems certain that the greater heat of Missouri increases the rate of development and ripening more with the grape than with the apple. That seems to be true also with the peach as compared with the apple.

Overholser and Taylor (1308) suggest that in some of the valleys of California, the ripening of pears may at times be delayed by the very high temperatures.

Effect of summer temperature on the quality of the fruit. The summer temperature may influence markedly the quality of fruits, and the effect is not the same for all kinds. Many varieties of apples and most varieties of Labrusca grapes seem to be of better flavor when grown in the cool climate of New York than in a climate at lower latitudes. The acidity of flavor of some varieties of apples, such as Red Astrachan, seems much greater when they are grown in Missouri than in the cooler New York summer climate. On the other hand, most varieties of peaches are more acid in flavor when grown in New York and sweeter when grown in hotter summers. Thus, a sufficiently acid variety such as Champion seems much better flavored when ripened in the hot July and August weather of Missouri than in the cool September weather of New York. On the other hand, a very mildly acid variety such as Hill's Chili will be insipid when ripening during hot weather in Missouri and will have a more pleasant acid flavor when ripening later during very cool weather in New York.

The fruit of the apple is more commonly injured in quality by high summer temperature than is the fruit of most other kinds. In sections where there are very hot summer days, it is not uncommon for large killed areas to be found on the sunny side of fruits that are on the south and southwest side of the trees. Such exposure to the sun, however, during very hot days is sometimes injurious also to the fruits of the apricot and of some other kinds. It seems probable that this may be direct killing by high temperature. Overholser, Winkler, and Jacobs (1309) found the temperature of fruits exposed to the sun much above that of shaded fruits.

Shaw (1341) has described the effect of differences in summer temperatures on the form, color and quality of the fruit of different apple varieties. He seemed to find that, with winter apples, when the mean temperature for the period from March 1 to September 30 was only a few degrees above or below the optimum for a given variety, the texture and flavor, and sometimes the color of the fruit would be altered; when the mean summer temperature was lower than that which resulted in the best quality of fruit for a given variety, there was greater acidity, more astringency, less coloration, decreased size, and greater scalding in storage; and, when the mean summer temperature was a few degrees higher than that which with a given variety results in the best quality, there was uneven ripening, premature drooping, rotting on the tree, poor keeping quality, lack of flavor, mealiness, less intensive color and smaller size. Most of the characteristics which he lists as effects of a temperature below the optimum for a variety are evidences of immaturity. Some of the effects of a mean temperature above the optimum suggest a more advanced stage of ripening when picked; but others, such as the reduced color and flavor, it seems, can be explained only as an injurious effect on the fruit of high temperature. The influence of summer temperature, and of other climatic features on the time of ripening and the quality of different kinds of fruit is discussed in greater detail in Chapter 25.

Effect of summer temperature on the plant. The summer temperature to which the trees are exposed is an important feature in determining the distribution of fruits. Thus, it is well known that sour cherries, gooseberries, currants, American red and black raspberries, and many varieties of blackberries, require a cool summer climate and can be grown in low latitudes only when the summer temperature is mitigated by winds from bodies of water or when the altitude is high. It is difficult to determine what summer temperature is best for the trees of the average variety of apple, peach, plum, and pear, since so many other factors such as disease and winter freezing are of such great importance in determining distribution. All of these fruits, unless it be the pear, seem to find op-

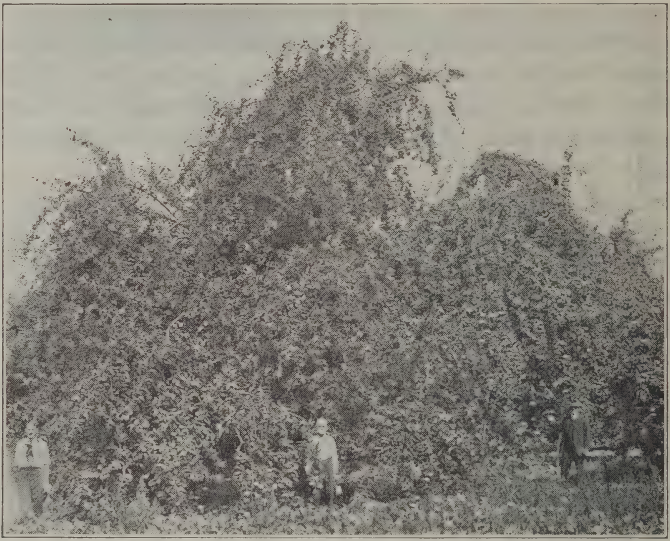

FIGURE 46. Tompkins King apple tree, 68 years old, belonging to T. D. Whitney, of Phelps, New York. Whether it is because of a greater freedom from diseases or of a direct influence of climate on longevity, trees in the northeastern part of the United States become larger and continue healthy to a greater age than in most other sections.

timum conditions for tree vigor and longevity in the climate along the Great Lakes in New York, Michigan, and parts of Canada. The vigor and length of life of apple trees there are very great. Thus, Warren (1156) found that in Wayne County, New York, latitude about 43.2°, apple trees reached their maximum production at forty-four years of age, and with good care an orchard would continue to yield profitably until it was seventy-five years of age or older. On the other hand, Auchter (930) found that trees began to decline at about thirty years of age in West Virginia (about latitude 37.2° to 39.5°) and in Virginia (latitude about 37° to 39°) a survey indicated that not more than two per cent of the trees are over thirty years of age. Only by very careful study could it be learned whether the difference is due directly to a difference in summer temperature; to the prevalence of insects or diseases that kill the trees; to heavier fruiting of the trees at the lower latitudes; to differences in the care of the orchards; or to some other cause.

It is conceivable that in some sections the temperatures of the wood may become high enough to kill some of the tissues. Thus, in California there are on the south side of tree-trunks or branches killed areas that do not seem to have resulted from the activity of any organism. In that State areas on the south side of a branch may, even in summer, be at a temperature of 15° to 20° F. above that of the air. And in other countries, the temperature of the tissue just below the bark on the sunny side of branches has been known to go as high as 131° F. At Davis, California, during the summer of 1921 the results shown in Table 65 were recorded.

TABLE 65. MAXIMUM TEMPERATURES ON EXPOSED PEACH BRANCHES

	HOTTEST DAY AUGUST 10	AVERAGE JULY 9 TO SEPT. 7
Air temperature in shade	116.6° F.	97.5° F.
Whitewashed trunk	118.4° F.	99.9° F.
One year wood (not whitewashed)	120.2° F.	103.5° F.
Main limbs (not whitewashed)	133.0° F.	114.4° F.

During the hottest day recorded, August 10th, the temperature on the sunny side of a branch was 16.4° F. above that of the air; and the average daily maximum temperature between July 9th and September 7th was 16.9° F. above that of the air. The soil water supply at Davis was very low at that time and it is probable that the transpiration stream moved very slowly during the afternoon. In sections where the water supply is abundant for rapid transpiration, it seems probable that a rather rapid movement of water through the wood of the tree might tend to reduce the difference between the air temperature and the temperature of the sapwood, and perhaps of the cambium, of the part of the branch exposed to the light. In parts of California, however, the water supply is lower in late summer than at Davis. And at Davis, there were days when the difference between the air temperature and temperature of the sunny side of the branch was greater than that on August 10; and so, it does not seem improbable that temperatures considerably above 133° F. may sometimes be reached on the sunny sides of exposed branches.

It is not possible to say what temperatures might be expected to injure these particular tissues. Pfeffer (1108) quotes the results of De Vries who exposed plants of a considerable number of species for fifteen minutes to high temperature. The killing temperatures were from 110° F. to 133° F. Waggoner (1155) found that radish seeds containing as much as forty-five per cent of water were killed at a temperature of 131° to 140° F.; while seeds containing as low as four tenths per cent of water required a temperature of 245° to 257° F. to kill them. Seeds containing an initial water content of nineteen per cent were killed by a temperature of about 149° F. when heated in water; while it required 212° to 221° F. to kill them when heated in an oven so that water could escape from them as they were heated. MacDougal and Working (1058) found joints of the prickly pear (Opuntia) to begin growth at 9° C. and to continue to 58° C. (136.4° F.), and the young joints were not killed at a temperature of 62° C. (143.6° F.). Of course, the cells of this tissue were in a succulent condition. The moisture percentage was probably as high as that of the radish seed killed by a temperature of 131° to 140° F. MacDougal and Working suggest that higher temperatures may be endured by tissues with a low content of salts than by tissues with a high content of salts (particularly salts of calcium, sodium, and magnesium); since salts of these substances might increase the tendency of the high temperature to coagulate the protoplasmic colloids. From the above observations it is clear that much depends on the condition of the tissue when exposed to the high temperature. It does not follow, however, that because a given tissue will withstand a few hours exposure to temperatures as high as those which radish seed and prickly pear joints endured, they will withstand without injury long continued, or, perhaps, repeated exposure to such temperatures. Balls (937), working with the "sore-shin" fungus of cotton, found that the growth rate was accelerated with rising temperature, in accordance with the expectations of Van't Hoff's law until the temperature of 30° C. was reached, when the acceleration decreased. Growth stopped at 37° C. or a little higher. With one culture there was slight growth up to a temperature of 40.5° C. Growth stopped at a lower temperature if the fungus had been held at a temperature of 22° C. to

33° C. than if it had been held at 20° C. He thinks that with long-continued growth particularly at high temperature, there are formed katabolic products in the cells that inhibit growth. At 35° C. there was only slight growth of this fungus in the stem of cotton seedlings in air, but when the seedlings were partially submerged in water there was at that temperature a good growth of the fungus in the tissue at the water level. He thinks that the water dissolved away the injurious katabolic substances. If, at high temperatures, plants generally formed injurious substances, it seems probable that in dry, hot, sunny climates the tissue on the south side of the branch might be injured by the accumulation of such injurious substances due to the daily exposure to unusually high temperatures, the accumulation of such substances possibly being more rapid because the water supply in the soil is so low that the transpiration stream is very sluggish, the tissue possibly not being nearly enough saturated even during the night to carry away such injurious products. Of course, this work of Balls is only suggestive; and summer sun scald and other high temperature injury may result only when the actual killing temperature of the tissue is reached.

Whether or not there is direct killing by high temperature of other tissue than that on the sunny side of young fruits, we can be certain that temperatures such as those recorded in Table 65 are above the optimum and perhaps above the maximum for growth of some species. The summer temperature responses of some of the different kinds of fruit trees will be discussed in Chapter 24.

Summary. The length of daily illumination may be of great importance in bringing about a condition of fruitfulness. With some plants long days seem necessary for fruiting; with others short days; while with others the length of daylight does not seem greatly to influence fruiting. There is no significant evidence that length of daylight is of any importance in determining fruit-bud formation with any kind of deciduous or subtropical fruit; however, there is no conclusive evidence that it is not of some importance among other influences. The time of blooming of deciduous trees can be influenced but little if at all by the length of daylight.

Unless the temperature is excessively high in latitudes as low as 33° to 38°, or in sections influenced by warm ocean winds, the greater length of the yearly period warm enough for growth is the cause of greater annual growth of young trees; but it is not certain that it has such an influence on older trees or that it increases fruit-bud formation. At latitudes below 35° to 36° in the Atlantic Coast region, 36° to 37° in the Mississippi Valley, and 40° to 41° in the Pacific Coast region, except at rather high elevations, the trees of some kinds of fruit are not fully out of the rest period when spring weather warm enough for growth begins; and blooming is delayed by that condition. Above those latitudes blooming is about five days later for each additional degree of latitude. In the United States the different deciduous fruits bloom more nearly together at high latitudes than at lower latitudes. This may be due in part to differences in the length of the rest periods of different kinds; but is due in part, also, to the fact that on account of the greater length of daylight at blooming time in higher latitudes the mean temperature during the time of opening of the blossoms tends to be higher. The sum of daily mean temperatures above a basal growing temperature (the "physiological constant") is greater at low than at high latitudes, because at low latitudes there are preceding blooming time more days in which the temperature is above the basal temperature but not high enough for more than very slow growth, and because at the low latitudes there are many days warm enough for growth while response by the trees is still prevented or inhibited by the rest period.

The blooming time of the tree is influenced to some extent by the pigments in the wood. During bright sunlight the temperature of dark colored twigs may be considerably above that of the air.

A difference in summer temperature influences to different extents the ripening dates of different species and varieties of fruits, and influences differently the nature (color, flavor, and quality) of different kinds of fruits.

The rather mild summer temperatures prevailing in the northeastern part of the United States seem to be responsible for a longer life of some kinds of trees such as the apple; but other features, such as the absence of serious bark or wood diseases, may be concerned. It is not known at what temperature tissues of fruit trees may be killed by heat; but it is certain that some young fruits, especially young apples, are sometimes killed on the sunny side; and it seems probable that summer sun scald of the trunk and branches may be a direct killing by heat. A temperature of 133° F., known sometimes to be reached on the sunny side of branches, is above the killing temperature of some plant tissues when turgid.

CHAPTER 21

FREEZING TO DEATH OF TISSUES

The freezing to death of tissues of fruit plants is important not alone in determining the distribution of the fruit industry, but also as one of the greatest sources of loss in the fruit business. At the time of most rapid growth in summer all tissues of the tree may be killed by a temperature not many degrees below freezing. With all tissues the resistance to freezing increases throughout the summer, and even after leaf fall, until some will withstand a very low temperature. Macoun (1063) mentions a hybrid between *Pyrus baccata* and *Pyrus Malus* that withstood a temperature of −58° to −59° F. Most varieties, however, would be killed, even in their condition of greatest resistance, at a much higher temperature than that. When very succulent tissue, such as that of leaves or of blossoms, is killed by freezing, it becomes flaccid after thawing, and has a brown water-soaked appearance. In woody tissues, the flaccid condition naturally does not show, but the brown water-soaked condition is characteristic, especially after the tissue has been thawed several days. However, with such woody tissue, to learn the extent of the killing requires microscopic examination. To the unaided eye a tissue may appear entirely brown when with the aid of the microscope it will be found that many cells are alive — or with the aid of the microscope areas of dead cells may be found in tissue that to the unaided eye appear uninjured. There is a great difference not only in the temperature that the different species and varieties will withstand, but also in that which different tissues of the same plant will withstand. Further, the relative resistance of the different tissues of a tree is not the same under all conditions of growth and maturity. It seems best, therefore, to discuss separately the killing of each kind of tissue.

Killing of pith. Generally, of the woody tissue above ground, the pith is the most liable to be killed. In so far as we know, the only harm that this may do is to rob the tree of some storage materials. Pith in thickened spurs like those of the pear, is very commonly killed, and such killing may cause the growth from a spur to be weak. On a few occasions I have known the killing of the pith at the base of peach buds to delay the blooming, though normal crops were later set from such buds.

Killing of sapwood, cambium and bark. When the wood of the trees is well-matured, sapwood is less resistant than bark. Killing of sapwood materially reduces the water supply, and as result the growth in the following year may be very weak. With apples, pears, peaches, and cherries, killed sapwood is a very common form of injury. With some varieties of apples, killing of this tissue is most likely to be found in the twigs and smaller branches, while with others, such as Ben Davis, the injury may be greatest near the base of a main branch. For example, following the severe winter of 1917–18 in New York, the killing of the sapwood of Baldwin and Rhode Island Greening trees was more serious in the spurs, twigs, and younger branches, while the twigs and spurs of Ben Davis showed very little browning. The initial growth of the Baldwin and Rhode Island Greening was weak, the leaves being much below normal in size. Later in the summer, however, there was improved growth, particularly on the lower part of the branch. Often there was a second twig growth in midsummer or later, which should be expected to improve the water conducting power of the tree. With Ben Davis, however, the initial leaf growth was apparently normal; but soon after the leaves were fully open they wilted. In such branches it was found that the sapwood was badly injured at the bases. It seems probable that the leaves were able to open normally because of the reserve water supply in the branch and the amount that could pass the dead tissue, but that when they were open and transpiration had become rapid the water supply was inadequate. Or it may be that substances from the large mass of killed tissue injured the parts above. Sapwood that is frozen to death is much less resistant to the growth of wood-destroying organisms than is uninjured sapwood or normal heartwood; and any such injured wood that is exposed to the air rots rapidly. Further, it has much less strength than has normal sapwood or heartwood. If the cambium is uninjured and a new layer of sapwood covers this injured wood (which is often called "black heart") little harm may be done; provided all wounds where injured wood is exposed are thoroughly painted. Young trees in the nursery that have had the sapwood badly injured will seldom survive transplanting in the spring following the injury. After a year's growth, when a new layer of sapwood is formed, they may be transplanted without serious loss.

When the wood is well matured the cambium is one of the most resistant of tissues. With peaches and pears and sometimes with apples one may find the sapwood and bark brown throughout and yet the tree may live. In fact, following the cold winter of 1917–18, peach trees in New York, which to the unaided eye appeared to have no living tissue above ground, formed a new layer of wood and bark and in some cases new sprouts from dormant buds on the branches and made as much as three or four feet of growth. Often, too, on trunks and branches of apple trees the bark seemed dead to the sapwood and yet later in the summer a new layer of bark was found under this old dead bark. On the other hand, the cambium may be killed when the injury to the bark and sapwood is not great. Mix (1085) reports observations of living bark being separated from sapwood at the base of the tree, this sapwood having been killed. Whether or not the cambium also was killed could be determined only by a careful examination with the microscope.

With a tree that has gone into winter with all tissue well matured the bark seems more resistant than the sapwood. However, the bark is often killed, particularly in positions unfavorable for the development of resistance. The outer part of the bark may be killed in spots when the remainder is uninjured. Such areas are often called "superficial bark cankers." This dead bark is eventually sloughed off and no measurable harm is done. In fact, it is only when the cambium is killed that the injury is permanent.

Crown rot. The bark, cambium and sapwood at the base of the trunk are often less resistant than at other points. Studies (967, Mix 1085) have shown that at this point the tissue matures more slowly than it matures higher in the tree. When areas of bark and cambium are killed in this position the injury is often called "crown rot." Sometimes only a narrow ring of bark at the base of the trunk is killed, while on some trees, particularly young ones trained to high heads, killing may extend several feet up the trunk, the severity of the injury decreasing upward. Headden (1027) has attributed injury of this kind on trees in Colorado to arsenical poisoning. Grossenbacher (1016), however, suggests that the mere finding of arsenic in the tissue is not proof that it caused the death of the tissue. Further, he calls attention to the fact that in some of the photographs published by Headden there is rather luxuriant growth of vegetation around the injured tree. Crown rot is found on trees in such low latitudes that it seems doubtful if it can always be due to low temperature. Grimes Golden apple tree, in the Ohio River section about latitude 38° to 39° often have what is generally called "collar rot" around the base of the trunk. In New York, in the winter of 1917–18, this variety did not seem to be injured at the base of the trunk or elsewhere; and, since this injury probably results from immaturity, it seems that it would be more liable to be found in New York than at lower latitudes. The injury to Grimes Golden trunks may be the result of some kind of organism or of physiological influences other than freezing. However, heavy fruiting delays maturity of the wood, in the trunk and elsewhere; and, of course, it is possible that such heavy fruiting of this variety might cause the wood at the base of the trunk to be at such low resistance as to be killed by freezing even below latitude 38°. Further, in Ohio River sections there is more danger than in New York that, during a very cold night, the base of the trunk will not be protected by snow. There is seldom killing below the snow-line.

That such injury in high latitudes is generally caused by freezing has been shown rather conclusively by Grossenbacher (1016), Mix (1085), and by a number of others. It was abundantly demonstrated by the severe winter of 1917–18 in the northeastern part of the United States and in Canada. Fresh injury observed by early spring ranged all the way from small spots at the base of the trunk to injury covering the entire tree.

The sapwood as well as the bark may be more tender at the base of the tree, and in some cases of "crown rot" the bark is not frozen to death, but is merely separated from the dead sapwood; and, since cambial growth ceases the bark eventually dries to death.

Sun scald. Under some conditions the injury is found only on the south or southwest part of the trunk or of branches. Such injury is often called "sun scald." We have seen in Chapter 20 that similar injury is found on certain trees in California in sections where at no time is the temperature low enough to kill the wood; but in cold sections it is often, if not always, a form of winter injury. Many workers have shown that, with dormant plants after leaf fall, dark-colored tissue in direct sunlight may absorb heat enough to maintain a temperature considerably above that of the air. At Ithaca, New York, Mix (1085) found the temperature of the inner bark and outer sapwood of the southwest side of a tree as much as 39° F. higher than that of the northeast side. With a tree-trunk blackened with tar, the temperature on the same day (February 20, 1915) was 57° F. higher on the southwest than on the northeast side of the tree. Müller-Thurgau (1088) suggests that this higher temperature of the tissue on the sunny side may cause it to approach a growing condition and thus become less resistant to freezing. Mix found no indications of cambial growth on either side of the tree as late as April 13 at Ithaca, New York (latitude 42.5°). On May 2d there had been some growth, but apparently as much on the north as on the south side of the trunk. He froze also pieces of bark, cambium and sapwood at intervals during the year. At no time, not even as late as April 12th, did he find the tissue on the southwest side less resistant than that on the north side. And even as late as March 31st, a gradual temperature fall to −27° F. caused very slight injury to the tissue on either side of the tree. It seems certain, that a starting into slight growth is not the cause of the killing of the tissue on the southwest side of the tree. Chandler (967) suggested that on a cold clear day the tissue on the southwest side of the tree might gather heat enough to melt all the ice in it, while the tissue on the other side might be far below the freezing point; and that very quickly after the direct sunlight ceased to strike this tissue its temperature might drop to that of the remainder of the trunk. On February 14, 1916, Mix observed a fall in temperature of the tissue on the southwest side of a tree from 31.5° to 6.0° F. within one hour. He could always kill most of the cells of bark, cambium, or sapwood by exposing them, at once, to a temperature of −4° F., a temperature at least 25° F. above that at which it would be killed if the temperature fall were slow. He did not observe actual "sun scald" resulting from the rapid temperature falls observed. This would be expected to result only when a very cold night followed an afternoon so clear that the heat gathered on the southwest side of the tree would thaw that tissue. Such coincidences would naturally be rare in any one orchard. In fact sun scald seems to occur rarely in any one orchard; but a considerable percentage of the trees may be affected at one time. Thus in a large orchard of McIntosh apple trees near Schuylerville, New York, in the spring of 1920, many of the trees were found to show "sun scald." Other parts of the trees than the southwest side were entirely uninjured. Mix found that keeping the trunk of the tree whitewashed at the base would prevent its acquiring a temperature much above that of the air. It seems probable that this treatment might prevent sun scald. Harvey (1025, 1026), using thermocouples, which are more quickly responsive to temperature changes than mercury thermometers, has studied the temperatures of cambium on the sunny side of trees with bark of different colors. He found in clear sunlight much higher temperatures on the sunny than on the shaded side of the trunk or branch; and a very rapid temperature fall when something was placed between this warmed tissue and the sun. He suggested that on this account there is much fluctuation in the temperature of the south side of the trunk or exposed branch; every passing cloud causing a dropping of the temperature of such exposed tissue to that of the shaded side. It does not seem probable that such fluctuating temperatures during the day could do much, if any, harm unless during the night following such a rapid fall in late afternoon a temperature should be reached at which, with that rate of fall, the tissue would be killed.

Crotch injury. The bark on the inner sides of branches is often killed when other parts are uninjured. The killing may be only at the base of the branch as shown in the accompanying figures, when it is generally called "crotch injury." It may, however, extend far up the branch on the inner side. If, during the previous spring or summer, there has been a secondary branch removed from the inner side of the main branch, a strip of tissue from this point down to the crotch may be frozen to death. One often finds in the literature the statement that "crotch injury" is caused from the lodging of snow and ice in the crotch. However, such injury often occurs in positions where ice could not lodge. Thus, it often extends far up the branch and may be on the side of the branch rather than directly in the crotch. Further, with branches that bend downward so that their secondary branches are only on the upper side, killing of the bark is generally on the lower side. This was specifically observed on Ben Davis and Northwestern Greening apple trees in Wayne County, New York, following the cold winter of 1917–18. The maturing of the wood and bark seems to proceed more slowly on the inner side of an upright branch, and on the lower side of a downward bending branch. This seems to result from the fact that with the upright branch there is less foliage on the inner side, the secondary branches having been shaded off, and with the downward bending branch the secondary branches with their foliage are mainly on the upper side. Probably because of this lack of foliage on the injured side of a branch such wounds heal very slowly. Thus, in New York orchards, the larger crotch wounds caused by the cold winter of 1917–18 had not been fully covered by the summer of 1922; though many of the smaller ones had been covered by the summer of 1921.

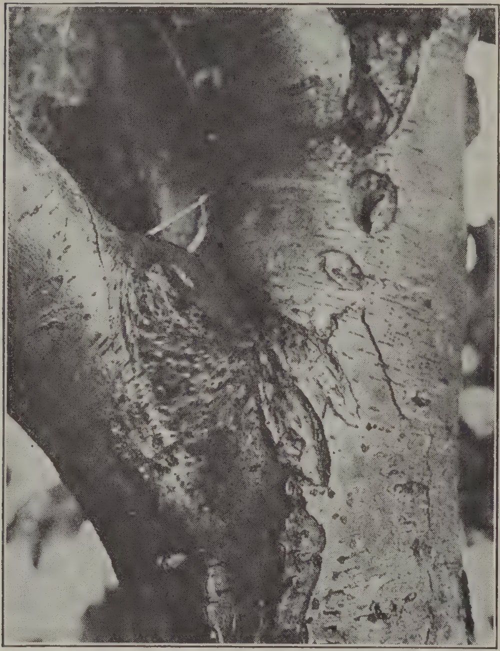

FIGURE 47. Crotch injury before dead bark is removed.

Winter killed sapwood has very little strength; and so if the sapwood as well as the bark in the crotch has been killed the first crop borne by the branch after the injury is liable to split it down. Even if the sapwood is not killed, since the cambium is dead, there is no new tissue developed on the upper side of the branch directly in the crotch. Yet the branch is growing in weight and in bearing surface. We have seen in Chapter 18 that the knitting of the new tissue in the crotch is very important in giving strength of union to the branch. Even the largest crotch injuries may eventually be covered by new growth, if the branch is prevented from splitting down. In the summer following such injury in the crotches with kinds such as the apple, the trees of which are permitted to grow rather large with long heavy branches, all injured branches should be braced by means of a system of cross wires. Of course, the injured area should be kept painted. However, the bark is often killed when the cambium under it is uninjured; and so if the bark is removed and the wound painted in the spring following the injury the wound may be much larger than if the dead bark had been left on the tree until the second spring following the injury. In New York, following the winter of 1917–18, in much the larger number of cases the cambium under the injured bark was not killed; or the area of killed cambium was considerably smaller than the area of killed bark. Further, under this killed bark, when the cambium also was killed, the callous growth around the areas of killed cambium seemed to spread and cover the wound faster than it spread if the dead bark was removed in the spring after the injury. Very satisfactory results followed when the dead bark was removed and the uncovered sapwood was well painted in the second spring after the injury.

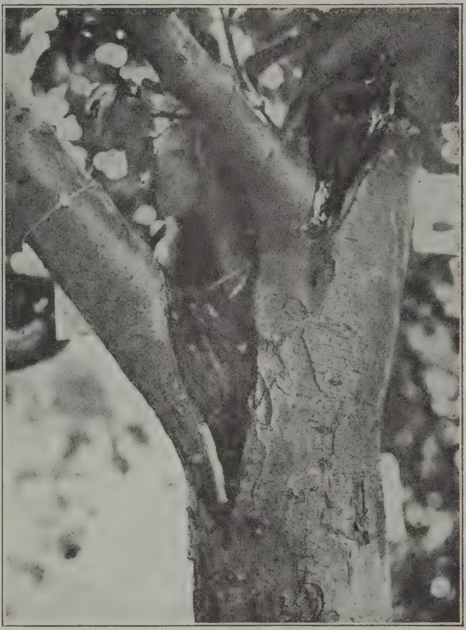

FIGURE 48. Crotch injury after removal of bark and painting.

Splitting of the trunk. Another form of injury is a splitting of the trunk. Wood is often split to the center or nearly through, and the bark often curls back, making the wound wider. It may soon be covered with callous tissue, however. According to Müller-Thurgau (1088) this splitting is caused by a tension in the tissue due to the fact that, as the water moves out of the cells to form ice in the intercellular spaces, the continuous woody tissue from the center out prevents shrinking of the wood toward the center; the less rigid medullary ray cells permit shrinking tangentially. Drying of the wood may cause similar splitting or cracking. It seems possible, however, that the expansion of the ice in the inner part of the tree may be responsible. Craib (413) seemed to find that water in the tree is most abundant in the center during the winter months. It may be that under some conditions this non-living wood is saturated with water; and since there is very little material in solution in such noncellular water, the ice masses formed may be very rigid. The expansion of such ice masses might cause the splitting at the surface, the condition favoring such splitting, if this theory should be true, would be saturation or near saturation of the heartwood and older sapwood.

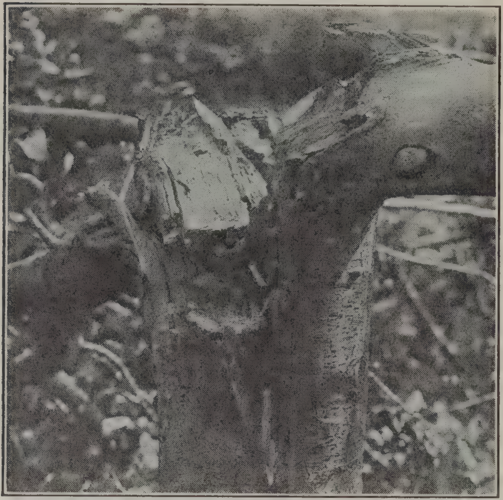

FIGURE 49. Summer following severe injury in the crotches. Note that some of the wood breaks sharply across instead of splintering like uninjured wood. Durable bracing with cross-wires is necessary with bearing trees having crotch injury.

Killing back of twigs and young branches. While it is true that often the wood in the crotches or at the base of the trunk is the least resistant it is also true that, with young trees, especially if the freezing weather occurs in the fall or very early winter, the worst injury may be in the tops of the trees, the twigs and possibly the parts of the branches that are only two years old. More often it is in the twigs alone, especially on the distal ends of long ones.

Killing of vegetative buds. Generally, vegetative buds seem to be about as resistant as cambium. There are conditions, however, when they are apparently more tender than other tissue. The killing of these buds has had very little study, perhaps because it is not very common. There are a few observations, however, that are of interest. Thus, in a peach section in northern Ohio during the winter of 1917–18, according to Professor Paul Thayer, who furnished the photograph shown in Figure 50, ninety to ninety-five per cent of the vegetative buds were killed, though fruit buds survived. As the figure shows, fruit was borne on twigs and small branches containing no leaves. Evidently, if there was sufficient living tissue in the twig to conduct water, organic food and mineral nutrients to this fruit, it could have supplied water sufficient for the growth of leaf buds if they had been alive. This killing temperature came early in December, before the trees had reached the condition of greatest resistance. Apparently the leaf bud tissue hardened the most slowly. At the Cornell Experiment Station it has been the custom to place trees purchased in the fall in a cold storage plant where the temperature is held between 32° and 40° F. At those temperatures there was more growth around the buds than at other positions; and in one spring there was freezing weather after the trees had been removed from the storage and "healed in" in the orchard. The leaf buds, with some of the tissue around them, were killed, though other parts were injured little, if any. These are exceptional cases, however, and generally the leaf buds are relatively very resistant. Even in some of these cases it is possible that the leaf buds were not frozen to death, but died after supporting tissue had been killed.

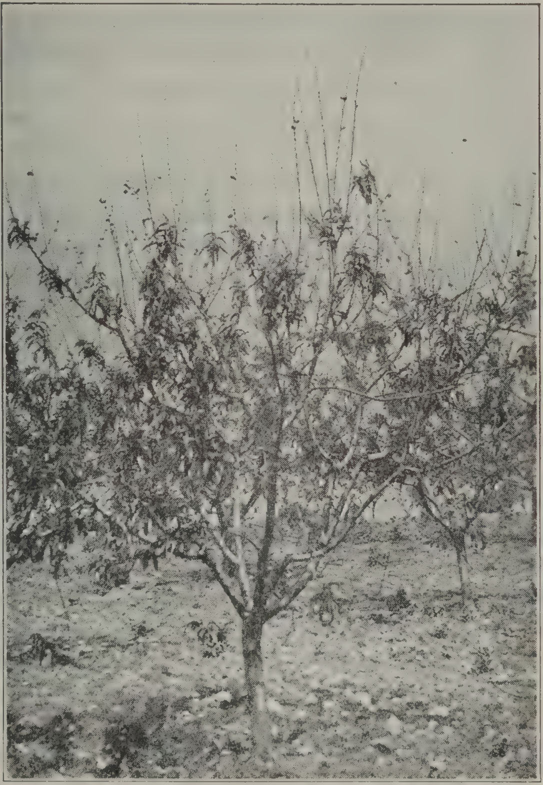

FIGURE 50. Photograph by Professor Paul Thayer in northern Ohio in the summer of 1918. Note peaches being borne on twigs of which the wood buds were killed by the severe winter. (After Thayer.)

Killing of fruit buds. The fruit buds of some kinds such as the peach, apricot, cherry and Japanese plum, in the average year, are less resistant to low temperature than are the other important tissues above ground. This is not true under all conditions, however; for sometimes even with the peach the wood may be badly killed when the fruit buds have not been injured. With the sour cherry and the Japanese plum there are great variations in hardiness, depending upon the nature of the growth during the summer preceding the cold winter. Roberts (1123) found that the farther the flower parts have developed when winter comes, the more tender sour cherry buds will be. He seemed to find that the degree of differentiation of the bud at the end of the growing season depends upon the time that initiation of flower parts begins and the rate of development as determined by the size of the subtending leaf. Thus, on the short spurs flower part formation begins early in the summer; but because of the very small leaves the differentiation proceeds slowly. These spur buds are, therefore, generally the most resistant to low temperature. Buds on long vigorous twigs also are resistant, the initiation of flower parts beginning so late that an advanced stage of development is not generally reached before winter. Buds on twigs four or five inches long are generally the least resistant. On these twigs growth ceases early enough for initiation of flower parts to begin early; and, since the subtending leaves are rather large, the development proceeds more rapidly than with buds on spurs. When the tree as a whole is considered, the conditions that favor the initiation of flower parts early in the summer favor the killing of the buds the following winter. Following a dry summer, the buds are in more danger of being killed. If the twig growth on the tree is prolonged in summer by good cultivation, by having been pruned severely in spring, or by having been fertilized with nitrogen, the amount of fruit-bud killing is reduced. Roberts (1124) found more killing in tissue, many of whose cells had large central vacuoles, than in tissue in which most of the cells seemed to be almost completely filled with dense cytoplasm. Flower buds in an advanced stage of differentiation were found to have a larger percentage of the cells vacuolated.

The flower buds of the Japanese plum also are rendered more tender by summer conditions favoring early initiation of flower parts in the buds. During some winters when the temperature does not fall much if any below 0° F., the buds may be killed if the summer has been a dry one, or if the trees have been in sod. On the other hand, in the winter of 1917–18 many buds survived a temperature of $-25°$ F. or lower, the previous summer having been too short for fruit-bud differentiation to proceed far before winter.

As to whether or not the degree of differentiation of the buds when winter begins is of influence in flower buds of other fruits we cannot say with so much certainty. The flower buds of even the most tender varieties of apples and pears withstood the severe winter of 1917–18 well, even though the wood was badly injured. Yet Whipple (1164) reports serious injury to apple and pear buds when the temperature had not been lower than −24° F. Whether the preceding summer was one favorable to the differentiation of the fruit buds to a greater degree than usual he does not say. I have observed many fruit buds of Jonathan apples to have been killed in the Ozark region of Missouri; but they were on trees in sod in poor land and were probably in an advanced stage of differentiation. This suggests the same behavior as that of the sour cherry and the Japanese plum. However, Bradford (955) found flower buds of the Jonathan apple killed in December, 1921, at Columbia, Missouri, when the temperature had not been lower than 7° F. Most of the killing was in twig terminal buds. Since the killing was in early winter at a temperature far above the minimum which, normally, the buds will withstand, since it was worst in twig terminal buds that are generally later than others in differentiation, and since the rainfall of August, 1921, was high and that of September nearly twice the normal, he thinks the killing was due to immaturity. However, he does not give records as to the condition of the trees in June, when flower-bud differentiation would be expected to begin; and he gives no data as to the stage of differentiation of flower buds when winter began. The orchard was in sod; and so early beginning of flower part differentiation might be expected. Further, the abundant rainfall of September followed by a rather warm October might be expected to contribute toward the development of an advanced stage of differentiation. Even though differentiation might begin later in terminal buds, it is possible that in that advantageous position it might proceed more rapidly than in other buds and reach a more advanced state by cold weather. It is possible, further, that these terminal buds were less completely in the rest when the abundant rainfall began; and that differentiation could proceed with less inhibition from the influence that causes rest. Of course, even if the buds were in an advanced stage of differentiation, it is possible that the protoplasm was also in a succulent, immature, or unhardened condition when winter began. However, the condition of being hardened or mature generally develops earlier in the flower buds than in the wood. Thus, in the winter of 1917–18, when the killing of the wood was entirely because of an immature or unhardened condition, flower buds were generally uninjured on trees the wood of which was almost all killed. While we cannot say from careful study that the killing of apple and pear flower buds is favored by an advanced stage of differentiation as in the case of flower buds of the cherry and, perhaps, of the Japanese plum, it seems probable to me that it is. Whipple thinks that much killing of apple and pear flower parts in winter may be overlooked, since even if these are killed the bud may still open into a whorl of leaves. When the buds open the dead flower parts are so inconspicuous as to be overlooked by the casual observer.

The growth of the buds during warm days in winter is increased by the absorption of heat by the color pigments in the twigs; and Whitten (1165) found that when twigs were kept covered with whitewash so that they reflected the sun's rays and thus during sunny days remained at a temperature but slightly above that of the air, the buds made appreciably less growth during warm late winter days. In fact, crops of peaches have been obtained on trees so whitewashed, when the buds were all killed on adjacent trees that were not whitewashed. It would seem that this might be just as important for other fruits, such as apricots, cherries and Japanese plums, whose buds are liable to make a harmful amount of growth in winter. However, the amount of fruit saved might not justify the rather large annual expenditure.

The buds are enclosed by many scales. Wiegand (1169) has suggested that these scales can offer little protection against low temperature, the temperature within the bud following closely that of the air during even rather rapid temperature fall. At the University of Missouri (967) the scales were removed from buds of the peach, and these were frozen in the same chamber with buds containing the scales. There were more than 4400 buds of each kind; the average percentage killed of those with the scales off was 51.0 and of those with the scales on was 68.5. The scales, of course, protect the buds from loss of moisture during warm or cold weather.

Killing of blossoms and fruit. In some sections, the killing of the blossoms and young fruits by late spring freezing is one of the greatest sources of loss to fruit growers. The statement is often made that there is a brief period just as the blossoms open when they are very tender and that if this period is passed there is less danger. Probably the opinion results from the fact that many people do not discriminate between actual killing of the blossoms by freezing and failure to set fruit due to the weather's being too cold for the activity of pollen-carrying insects. As a matter of fact, blossoms of most species will withstand an appreciably lower temperature when they first open than later. With the peach at least they continue to become more tender until the fruit is perhaps one half inch in diameter. On April 4, 1908, at Columbia, Missouri (967, p. 285) only twenty-four to sixty-nine per cent of fully open peach blossoms were killed by a temperature of 23° F., and Garcia and Rigney (998) in New Mexico observed peach blossoms to withstand a temperature of 24° to 26° F. Yet, on April 30, 1908, when the calyx tube had just fallen from the little peach five to eighty-five per cent of the fruits were killed by a temperature of 28° F. While the blooming time of early and late ripening varieties was the same, the fruits of early varieties such as the Sneed grew the more rapidly after pollination and were killed much worse by this freeze than were fruits of later varieties. With the young fruit the seed is much more tender than the other tissue and sometimes only the seed is killed. The fruit will appear uninjured for a time but will fall without making additional growth. Apple blossoms do not seem to decrease in resistance, after pollination, as rapidly as do peach blossoms. Apple blossoms are generally less resistant than peach blossoms, while the young fruit seems to be as resistant as peaches of the same size.

With most fruits the open blossoms are generally more tender than at any preceding stage; but this may not always be true. With sour cherries, and, under some temperature conditions with apples and perhaps other fruits, there may be tender stages preceding complete opening of the flowers. At Ithaca, New York, during the spring of 1919, with Montmorency and Early Richmond cherry flowers that had not yet separated in the cluster, the whole flower being still enclosed by the calyx, the percentage of flowers killed was greater than with peach flowers fully open. With cherry flowers in this stage, as with the winter buds, it is very common for the pistils only to be killed, the remainder of the flower opening normally.

Dr. A. J. Heinicke observed that at Ithaca, New York, with apple blossoms, often the ovaries only are killed. In some stages of development of opening buds, of peaches especially but also of other fruits, the part of the style just back of the stigma is least resistant.

Nearly ripe fruits of late ripening varieties are sometimes killed by freezing. Of these the least resistant seems to be the Labrusca grape, though the peach, also, is very tender. Apples and pears may suffer no apparent injury at temperatures that render peaches worthless.

Killing of roots. The roots of fruit trees are, under normal conditions, surprisingly low in resistance when compared with the tissues above ground. While the soil never reaches as low temperature as the air reaches, tree roots are often killed. Goff (1009) seemed to find that the small end roots are killed back in the average Wisconsin winter. In midwinter apple wood may withstand a temperature as low as −40° F., while the roots would be killed by a temperature of about 9° to 12° F.; and the small roots would be killed by a still higher temperature.

This low resistance of roots seems to be due mainly to their growing below ground. Early in the summer of 1921, at Cornell University, the soil was dug away from around sections of roots of some peach trees; and some young apple trees were planted with parts of the roots above ground. These roots developed a surface resembling that of the trunk and branches. In the following winter these and roots that had remained covered were exposed during one night to a temperature of 13° F., and during another to a temperature of 3° F. The roots that had grown in a normal way below the surface of the soil were nearly all killed at 13° F., while the parts that had been uncovered during the summer were not injured at 3° F. As to whether or not uncovered root parts will become as resistant as other tissue we have hardly enough information to justify an opinion. It seems probable that they will become at least nearly as resistant; for parts of large roots that are uncovered during the summer are uninjured during very cold winters.

Carrick (963), studying the roots of young trees, in the different seasons of the year, as to their resistance to freezing, found the results shown in Figure 51. These roots, of course, had been grown in the normal way; that is, covered with soil.

Of course, there is hardly such a sharp increase in hardiness at the end of November, or the sharp decline in March. It is probable that if freezings had been made often enough a gradual increase in hardiness would have been found. These were generally seedling roots one to two years old. It is interesting to note the relatively great resistance of the roots of gooseberries and currants. Grapes of the species *Vitis vulpina* and *Vitis Labrusca* and the Mahaleb cherry also have roots that are very resistant as compared with those of the peach or the apple. Among the least resistant are the roots of *Pyrus communis*, *Prunus cerasifera*, *Prunus avium*, and *Prunus Persica*.

Chandler (967) found that long pieces of roots are less resistant at the smaller than at the larger end and in a branching root system, the smallest branches are generally the least resistant. Carrick (963) seemed to find the smaller individual apple seedling roots less resistant than the larger ones; but Potter (1115) working with larger numbers found no correlation between the size of one year old apple seedling roots, and their resistance. Individual seedlings varied much as to resistance. The roots with the most resistant upper parts had also the most resistant lower parts.

Craig (978) found, after a severe winter in Iowa, that scion roots of hardy varieties of apples were more resistant than the French seedling stocks on which the trees were worked. Mix (1085) and others

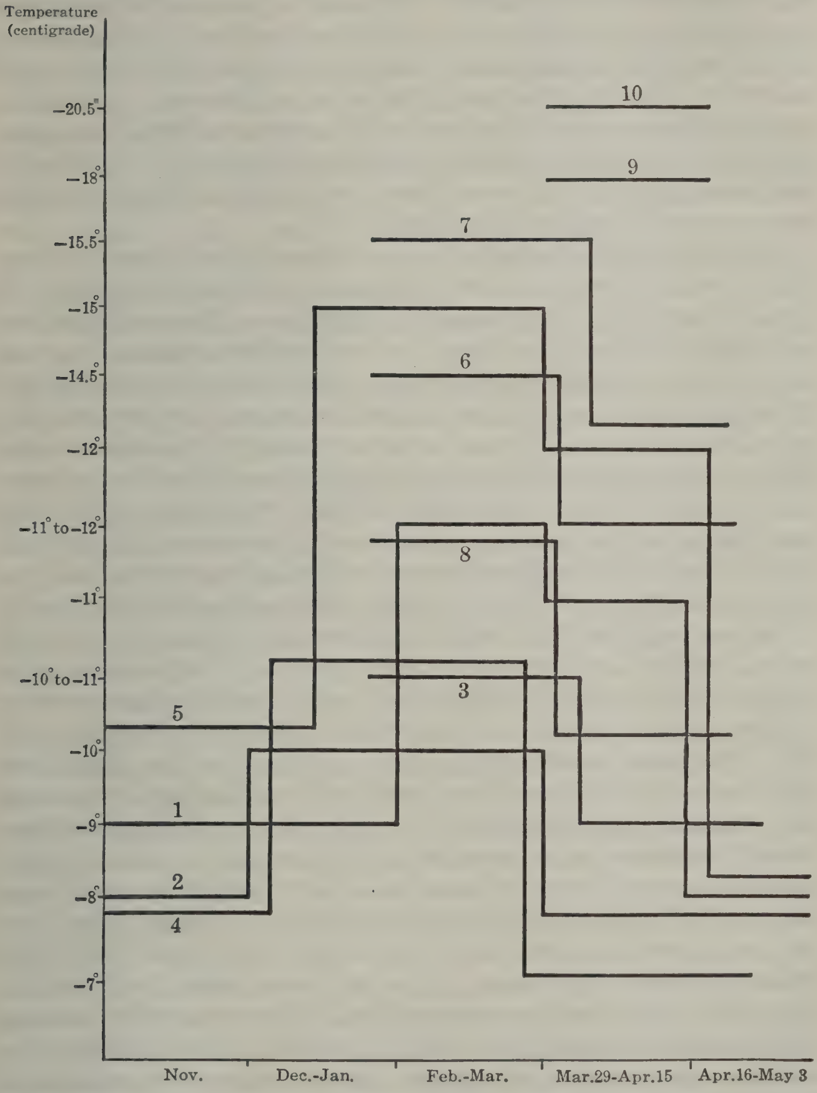

FIGURE 51. Seasonal hardiness of fruit roots. 1, Apple (French "crab"), and grape (Lindley, Norton, and Cynthiana). 2, Pear (French) and plum (Myrobalan). 3, Peach. 4, Cherry (Mazzard). 5, Cherry (Mahaleb). 6, Grape (Diamond). 7, Grape (Clinton and Concord). 8, Raspberry, blackberry, and dewberry. 9, Currant. 10, Gooseberry.

have found similar results. Potter found the scion roots of Oldenburg and Hibernal apple trees considerably more resistant than the seedling roots on which they were worked. He found a considerable variation as to the resistance of scion roots of different varieties. Scion roots of Dudley were less resistant, and those of Northwestern Greening considerably less resistant than those of Oldenburg or Hibernal. At the University of Missouri (967) scion roots of Wealthy and of Ben Davis apples were found more hardy than the French seedling roots. It does not follow that scion roots from a more tender variety such as Baldwin would be more resistant than these French roots.

When a part of the stock is below the surface of the soil during the summer it tends to become less resistant than the part above ground. At Cornell University in the summer of 1921, some Fameuse apple trees were planted so deep that about ten inches of the scion was covered. The soil was a very heavy Dunkirk clay. Other trees were planted with all the scion and some of the roots above the surface. The trees were dug in autumn and in the following winter were exposed during cold nights. With the deeply planted trees nearly all the tissue below the surface of the soil was killed by a temperature of 3° F. With these trees and the trees planted with all the scion above the soil, there was no injury to root or scion tissue that had been uncovered during the summer; and it is probable that the uncovered scion tissue would not have been injured by a temperature of −20° to −30° F. However, in the summer of 1922 young Jonathan apple trees were planted with ten to twelve inches of the scion covered, in a very light sandy soil; and in the following winter this covered scion wood was uninjured, when exposed to a temperature of 2° F. They were not exposed to a lower temperature; but young Jonathan trees, older Seckel pear trees, and Tompkins King apple trees about sixty years old had soil banked six or eight inches high around the bases during the summer and removed in early winter; and the tissue that had been thus covered during the summer was uninjured by temperatures as low as −15° F. In fact, it is probable that at but six or eight inches above the ground level the temperature was considerably below −15° F., the official weather bureau record. As to why being below the surface of a light sandy soil during the summer of 1922 did not reduce the resistance of these Jonathan apple tree trunks to the extent that being below the surface of a heavy soil in the summer of 1921 reduced the resistance of Fameuse apple tree trunks, and as to why heaping even heavy clay soil around the base of the large apple and pear trees did not seem to reduce their resistance at all, we cannot say. Neither do we know why root tissue or scion tissue growing below the surface of the soil is, under some conditions at least, much less resistant than when grown above the soil. It may be that the oxygen supply to the tissue during summer is influential as to the resistance developed. This experience suggests that merely heaping the soil around the base of the trunk during one summer at least, or in other ways excluding the light, does not tend appreciably to reduce the resistance to freezing that will be acquired.

Parts of the scion that have been below the soil several years seem always to have low resistance unless they are uncovered during a summer; and the formation of scion roots seems to reduce the resistance of covered scion parts. At Cornell University, young trees dug in late autumn were left with roots exposed during the winter of 1920–21. Temperatures as low as $-6°$ F. were reached. The roots were killed and also much of the scion tissue that had been below the surface of the soil during the previous summer. The farther below the surface the scion tissue had been the more tender it seemed to be. Some of these trees were from grafts with short seedling roots and long scions planted deep; many had formed scion roots. If the scion roots were mere threads no consistent difference could be found between the amount of killing of such scion tissue and that with scion tissue that did not form roots. However, where there was a scion root as much as one fourth of an inch in diameter, generally the scion tissue below it was injured worse than above it. While scion tissue that had grown beneath the surface of the soil was much less resistant to low temperature than that which had grown above the soil, it seemed never to become as tender as the French cider-apple roots. In higher latitudes trees are often found with the trunk killed just beneath the surface of the soil; often the killing is plainly just below the union of stock and scion. It seems probable that with hardy varieties of apples in such sections the amount of this kind of injury would be reduced if the trees were from piece root grafts; the scions being long enough for the original stock portion to extend far below the surface of the soil. If a hardy stock is available this precaution may not be so necessary. In well-drained soils deep planting may be a good precaution against root killing with young trees.

The condition and nature of the soil has much to do with the killing of the roots. Emerson (598), working with roots in boxes containing soils with different moisture contents found more injury to roots in soils low in moisture. He did not record the soil temperature. From what we know as to the latent heat of fusion, however, it seems certain that the temperature must have been lower in the dryer soil. Craig (978) reports that in Iowa during the severe cold of February, 1899 roots were injured most in sandy land, least in loam and to an intermediate degree in clay. This is in line with experience generally. In New York root killing is confined very largely to light sandy soils. It would be expected that such soils would reach lower temperatures than clay soils; and Bouyoucos (391, 392) found lower temperatures in light sandy or gravelly soils than in loam, clay or peat. It should be emphasized that the greater amount of root killing in sandy soils or in dry soils is due not to a reduced resistance in such soils but to the fact that the temperature is liable to be lower. Potter (1115) found that at the same temperature there was greater injury to roots frozen in wet than in dry sand. Carrick (963), Potter (1115), and Chandler (967) found wilting the roots, to increase their resistance to freezing.

Since during a cold period the temperature of the soil is far above that of the air, it is evident that anything on the surface of the soil that would prevent contact with wind would protect it against loss of heat. One often observes bare ground frozen when that under sod or under a thick growth of other materials is unfrozen. Emerson (599) found uncovered soil or soil protected by only a light cover-crop, such as rye or oats, frozen more deeply than soil protected by a thick upstanding cover-crop such as corn, sorghum or millet. The upstanding cover-crop holds the snow and thus increases the amount of protection to the soil against contact with cold winds. Bouyoucos (392) found at East Lansing, Michigan, on January 30, 1915, the following minimum temperatures three inches below the surface; for a bare soil, 7.5° F.; a soil covered with compacted snow, 15.6° F.; a soil covered with uncompacted snow, 27.0° F.; and for a soil covered with uncompacted snow and vegetation, 32.3° F. When average temperatures were considered, the differences were not great; but it is in the minimum temperature that we are interested here. For the tissue may be killed in a few minutes if the killing temperature is reached. From these data it seems certain that the nature of the soil and the thickness of the cover-crop are the most important influences in determining the amount of root injury. While the difference in minimum temperature of the different soil types is not as great as the difference between that of bare soil and soil well covered with snow and vegetation, it may be more important to the orchardist; for in some years the cold weather may be unaccompanied by snow and it may not always be possible to obtain a thick cover-crop.

The largest difference in hardiness of stocks among fruit trees studied is smaller than the difference in minimum temperature between sand and clay or loam, or between covered and uncovered soil. But, even if the cover-crop is good between the trees, it will seldom be thick around the trunk; and so if the snow blows away there may be killing of the trunk and large roots just beneath the surface, if the soil is a sandy one that freezes deep. Even in clay soils this sometimes happens. Therefore, in very cold regions, even if the soil is clay or loam and a thick growing cover-crop that stands high during the winter is used, it is desirable to use the hardiest good stock or to have trees with the hardy scion tissue extending well below the surface.

It is evident that in some cold regions the cover-crop should be left standing during the winter. We have seen in Chapter 13, however, that in some sections, trees seem to be benefitted by fall ploughing. It can be known as to whether or not it is safe to plough in the fall only by experience with the different soils in each section. Experience with fall ploughing during eight years, in some of which the winters were the coldest on record, suggests that, for a climate no colder than that of western New York, it is safe to plow in the fall a reasonably compact clay or loam orchard soil.

Factors that Influence the Amount of Injury by a Given Temperature

Maturing or hardening of tissue. At the beginning of this chapter it was indicated that the difference between the killing temperature of tree tissue, when it is most tender in early summer and when it is most resistant in midwinter or late winter, is very great, with some as much as 50° to 60° F., or more. The tissue in late summer is more resistant than in early summer when growth is most rapid, and in midwinter and later winter more resistant than in early winter, when the leaves are first off (967, p. 205). As to what specific changes in the tissues are responsible for this change in resistance we cannot say with certainty. Maturity in seeds is associated with a greatly reduced moisture content, and the resistance of seeds is greatly influenced by the moisture content. Ripe seeds containing little moisture have withstood the temperature of liquid hydrogen for six hours without injury. With woody tissues, however, reduction in the moisture content cannot be of much importance in the hardening process; for the moisture content of tree wood is not strikingly greater at the time the wood is most tender than at the time it is most hardy (967, p. 216).

The results in the northeastern part of the United States during the very cold winter of 1917–18 furnished valuable information as to conditions favorable to the greatest hardiness. The lowest temperatures were in December, before maximum hardiness had developed in many of the trees. Usually there was some killing in sections where the temperature fell as low as −15° F.; but, except with peach trees, serious killing was mainly in sections where the temperature fell as low as −20° F., or lower.

The previous summer was very short, trees blooming a month later than is normal. The season was also generally wet and cloudy, and the temperature below the normal in much of June, in early July and in September. Under these conditions young trees, except peaches, generally were killed worse in winter the more vigorously they had grown. With apple trees but three or four years old sometimes a checking of the growth in early summer, due even to the soil's being too wet for growth, resulted in greater resistance. With older apple trees and with young peach trees, however, healthy or rather vigorous growth seemed to encourage the development of resistance. With old bearing trees, an abundant nitrogen supply did not seem to reduce resistance, but in some cases seemed to increase it; perhaps by increasing the leaf surface.

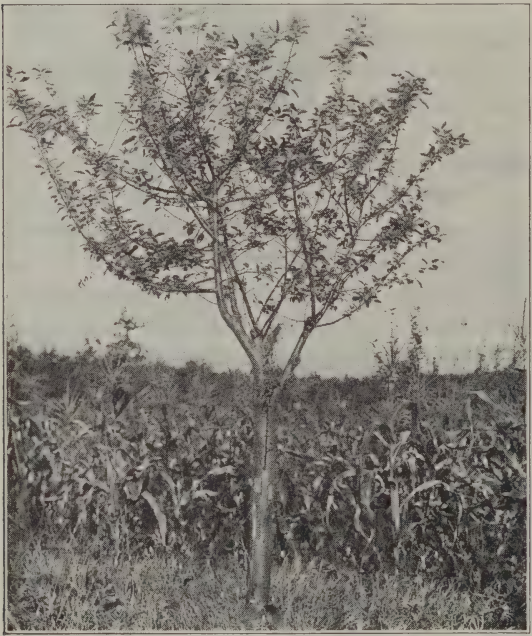

Figure 52. A Northern Spy apple tree top worked to Hubbardston, at Sodus, New York, two years preceding the cold winter of 1917–18. Trees with which the excess branches were left in the spring of 1917 were not injured; while trees like this one, from which all but Hubbardston branches were removed in the spring of 1917, were badly injured in the bark and sapwood of the trunks; the injury being worst toward the bases farthest from the foliage.

Certainly a healthy leaf surface was desirable. In every instance observed where, during the summer of 1917, leaves were removed by insects, spray-burn, or other causes, killing of the wood during the following winter resulted. Pruning rather severely, especially the removal of rather large branches, during the spring of 1917, often resulted during the succeeding winter in killing of tissue around the wound where the branch was removed; and sometimes strips extending from where the branch was removed to the base of the trunk were killed. In an orchard near Pultneyville, New York, Northern Spy apple trees, headed so high that the first branches were about four feet from the ground, had been top-worked to Hubbardston. With some of these the Northern

Spy branches, not top-worked, were removed in the spring of 1917, while with other trees this wood was left. These last trees, therefore, had larger tops and a larger foliage during the summer of 1917; and during the following winter they were uninjured, while nearly all the trees that had had the Northern Spy wood removed had tissue killed on the trunk. With all the trees the greatest injury was to the tissue at the base, farthest from the foliage. Both the Hubbardston and the Northern Spy wood in the branches was well hardened and uninjured. It seemed that proximity to the foliage determined the hardening of this wood. It was as if something moved downward from the foliage that in some way rendered the wood more resistant. In other orchards, large lower branches, with which, on account of the shade, there was little foliage to harden the large amount of wood, were killed on trees that were otherwise uninjured.

With young peach trees the wood may develop resistance very rapidly. At the Cornell Experiment Station in the autumn of 1916 some young peach trees were still in rather active growth by September 22d; yet these trees survived the winter in such excellent condition that during the following spring on 108 trees only six small twigs could be found that did not start growth from the end bud. We have seen in Chapter 1 that young peach trees have a very large leaf surface in proportion to the size of the tree. Older trees in the same orchard were injured by that winter. During the winter of 1917–18, old peach trees with very large trunks and branches were injured much worse than were younger ones. It seems probable that the leaf surface on these old trees was much smaller in proportion to the amount of wood to be hardened. It was also much farther from the trunk and bases of the branches. Apparently the larger the foliage in proportion to the amount of wood to be hardened the more rapidly the hardening process takes place.

Perhaps the most striking thing learned as a result of the cold winter of 1917–18 was the effect on the resistance of the wood of a heavy crop of fruit during the previous summer. Very many instances were found where trees that had a heavy crop during the summer of 1917 were badly injured during the following winter, while adjacent trees of the same variety that had little or no crop that year were uninjured. In Clinton County, New York, even Wealthy apple trees that had borne a heavy crop were killed to the ground; although similar trees of the same variety, not bearing in 1917, were uninjured. Figure 53 is of a Wealthy apple tree that bore heavily in 1917 and others that did not. It seems, then, that not only is some material elaborated in the leaves during late summer and autumn that, moving downward, renders the wood more resistant to low temperature, but that when the tree is ripening a heavy crop so much of this material may go into the fruit that, if the season is not a favorable one, the wood may not reach maximum hardiness.

The suggestion will at once occur that this may be the carbohydrates elaborated in the leaves. Naturally, these would be used largely by the fruit. This suggestion is in line with the results of Hooker (1033), Rosa (1127), and Newton (1092a) who found respectively that in mature resistant wood, in hardened vegetables, and in hardened wheat the pentosan content is much larger than in unhardened tissue.

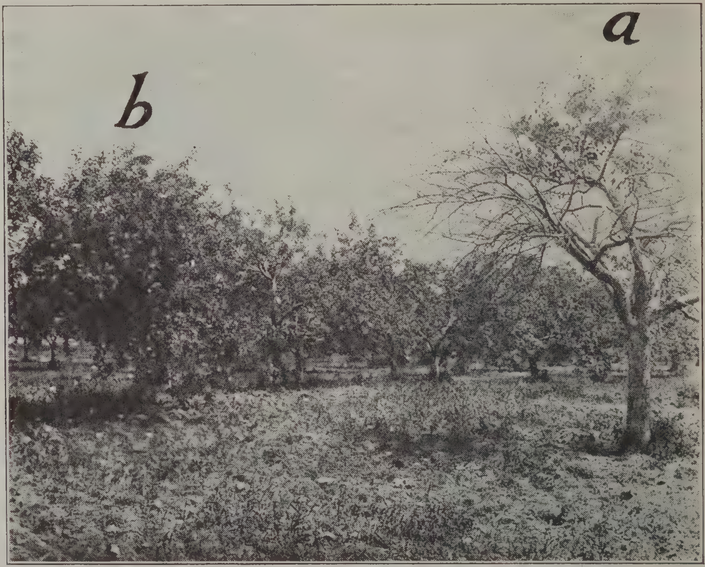

FIGURE 53. Wealthy apple trees at Plattsburg, New York, following the severe winter of 1917–18. Tree at *a* bore a heavy crop in 1917; that at *b* did not bear in 1917.

Roberts (701) seemed to find that as nitrogen is taken up by the plant there is a change in the composition of the tissue as to carbohydrates even before the supply of these materials can be used in growth. This suggests a possibility that if late in a summer trees that have ceased growth for that year should take up considerable quantities of nitrogen the carbohydrate composition of the tissue might be changed and its resistance thus, possibly, lowered. However, in the work of Hooker (633) and of Heinicke (627), when as a result of late summer application of nitrogen to the soil considerable quantities of that element were taken up by the trees, the resistance was not lowered enough to cause injury in a normal New York or Missouri winter. On the other hand, McDaniels

(862) found a narrower carbohydrate-nitrogen ratio in the tissue in the crotch of apple trees than in other parts of the same branches; and we have seen that this crotch tissue is often less resistant than the other tissue.

The interrelation of stock and scion as to maturity is of interest. It seems certain that the stock has little or no influence on the hardiness of the scion. It is very common, when a tender variety such as Tompkins King apple is worked on a hardy trunk, for the scion to be killed back to the stock. Dorsey (985) observed this in Minnesota; and it was very common in New York during the winter of 1917–18. This experience suggests, also, that the scion may have little influence on the stock. At least the stock may acquire greater hardiness than the scion. If the hardening process is influenced by material elaborated in the leaves, with a variety the wood of which matures early, such material moving downward from the scion might increase the resistance of a late maturing stock. Of course, it is possible that the ultimate nature of the material from the leaves is determined by the tissue concerned rather than by the leaves. And tissue of each variety seems to have a limit of resistance beyond which it does not develop regardless of how abundant the substances contributing to the hardening process. This may explain the cases of lack of influence of the scion on the resistance of the stock.

We have seen that the roots also have a hardening process, becoming more resistant in winter than in summer; though the difference in killing temperature in summer and winter is less with them than with the wood above ground. Mix (1085) found, in Clinton County, New York, that the roots of Ben Davis apple trees were injured worse by the cold winter of 1913–14 than were the roots of some other varieties. These were budded trees and there could have been few if any scion roots. Such results suggest an influence of the scion on the resistance of the roots. The influence may have been indirect, however. For example, if the Ben Davis had borne the heavier crop in 1913, then there may have been for the hardening of the roots less of whatever material from the leaves is influential in increasing the resistance of the whole tree.

Sometimes, when young trees, particularly of the cherry, make very weak growth in the first summer after transplanting, they are killed during the following winter, even though it be a very mild one. It is not certain whether the immature condition of this wood results from there being too little foliage adequately to harden the wood, or from a second cambial growth late in the summer. The latter condition sometimes occurs with weak trees. During the summer of 1914, the month of June was very dry in parts of the Hudson River section of New York, while in August there was abundant rainfall. In a very sandy soil at Kinderhook, pear trees in sod were killed badly during the following winter, though the minimum winter temperature at Chatham, the nearest weather bureau station, was only –15° F. The killing was worst in the cambial region, though normally this is the most resistant tissue. Evidently the dry weather had partially broken the rest period of these weak trees and they were in a condition to respond to the abundant autumn rainfall with a late cambial growth. Trees receiving good cultivation were not injured. By ending their growth later they were probably too completely within the rest period to be started again by the late wet weather.

Some succulent plants such as cabbage, wheat and rye when grown at a low temperature acquire great resistance, while if grown at a high temperature they are tender. It is possible that a similar behavior may be shown by fruit buds that have been pushed into growth by warm days in late winter or spring, and that buds which grow very slowly through many days at a temperature barely high enough for growth may be more resistant than buds that have reached an equal degree of development in fewer days at a higher temperature. It seems possible, also, that buds which have become rather tender as a result of rapid growth might, if held in that stage for a considerable period by a temperature too low for rapid growth, increase in hardiness just as cabbage or wheat plants would. Concerning either of these possibilities there is no very conclusive information.

While a low temperature seems to increase the immediate resistance of growing tissue in the way suggested above, it does not follow that low summer temperature is conducive to the most complete maturity and greatest winter resistance of the wood or buds. In fact, the reverse is true at least with some species. Thus, we have seen that during the winter of 1917–18, lack of maturity was very evident with many tissues, and the temperature during the preceding summer was below normal except during a part of July and August. It is not certain how much, if any, of the greater susceptibility to injury from low temperature was due to this cause; for the growing season was also shorter than usual and the water supply was generally abundant. In northern Missouri and in Iowa, where summer temperatures are higher than in the northeastern part of the United States, temperatures considerably lower than those which killed the trees in New York State are often withstood; but, again, difference in summer temperature is not the only difference between the growing seasons in New York and in Iowa. We have seen, however, that summer temperature is a very important feature in the ripening of fruit. It seems probable, but not certain, that the summer temperature may be of great importance also as influencing the rate of hardening of the wood of some kinds. For example, pecan trees and American persimmon trees seem to become more hardy in Indiana or northern Missouri than in New York; and, with the persimmon at least, it does not seem that the growing season can be longer in North Missouri than in western New York. For in Missouri, spring growth of the persimmon starts rather late and the leaves generally fall following the first frost. Such frosts usually occur as early in northern Missouri as in western New York.

We have seen that even after leaf fall the tissue may continue to increase in hardiness, at least during several weeks. It may be that long exposure to the low temperature causes dormant wood or bud tissue to become more resistant. However, flower buds of the peach seem to become as resistant in Georgia at latitude 33° as in Missouri at latitude 38° or in New York at latitude 43° (967); and the wood of most deciduous fruit trees certainly becomes as resistant in South Missouri, where there are seldom very long periods with no intervening warm days, as in New York where the mean temperature for November is generally below 50° F., and in December, January, and February, the temperature is below freezing most of the time. In fact, the wood of some varieties seems to become more resistant in Missouri than in New York. In California, deciduous fruit sections have the mean temperature for the three coldest months near 50° F.; trees of most deciduous fruits tend to continue growth later and to hold their leaves considerably later than in colder sections; and growing weather causes some reduction in hardiness within a few weeks after leaf fall; the wood of apples, pears, peaches, apricots, plums, and cherries does not seem to become resistant enough to withstand a temperature lower than about $-5°$ to $-10°$ F. As to whether or not this is due to the lack of a hardening influence of colder weather or only to the fact that the trees are not fully dormant long enough to acquire maximum hardiness, I know of no data.

Relation of the rest period to hardiness. The rest period may, by delaying the response of the buds to temperatures favorable for growth, influence their hardiness in late winter. Some think that the rest is associated with a condition of hardiness. Thus, Strausbaugh (1142) found with three varieties of plums that the variety whose buds would withstand the lowest temperature was also the one with the longest and the most profound rest period. He seemed to find that at the end of the rest period, even before there is any weather warm enough for growth, there is a change in the nature of the protoplasm; the tissue offering less resistance to the loss of water by evaporation. This may indicate a change in permeability. As a result of these observations and because the killing in Minnesota is generally after the ending of the rest period, Strausbaugh thinks that when the rest period ends there is reduced resistance to low temperature; whether there is warm weather to start the buds or not. It should be emphasized, however, that results with only three varieties can give little or no information as to a correlation between the length of the rest period and resistance to low temperature. In fact, it is certain that not all kinds with the longer rest periods are the more resistant. The peach certainly has a longer rest period than has the Japanese plum or the apricot, and yet unless the plums and apricots have been started into growth they are more resistant both in wood and bud than is the peach. And it does not seem probable that there is an appreciable decline in resistance at the end of the rest period unless there has been warm weather to start growth. The lowest temperatures that I have known peach fruit buds to withstand have been late in February after they were near enough out of the rest period to respond readily to growing temperatures. And Mix (1085) found at Ithaca, New York, no indications that the wood of apple trees is less resistant to low temperature at the end of March than in January. Yet, in March the trees would respond readily to temperatures favorable for growth. The beginning of the rest period is in late summer or autumn, and the most profound part of it, long before the tissue has reached the condition of greatest resistance to freezing. Regardless of the length of the rest period, it seems doubtful if there is any reduction in resistance of the tissue until there is warm weather enough to start the first protoplasmic changes in growth responses — whatever these changes may be.

Killing of tissue above ground may occur on a single night. It seems almost certain that when tissue is killed it is by the extremely low temperature of a single night. The length of the cold period is of only indirect importance as influencing the rate of temperature fall or the acquirement of resistance. That this is true of fruit buds is well known; for, repeatedly, buds have been taken following cold nights and found freshly killed. Such definite evidence is not so abundant concerning the killing of wood; and many think of the severity of a winter for fruit trees in terms of the number of cold days. By freezing in the laboratory, however, the wood is killed by exposure for a short time (one hour or less) to temperatures reached during severely cold nights. Potter (1115) found 27.5 ± 1.1 per cent of injury to apple roots held one half-hour, and 43.5 ± 1.2 per cent to roots held 17 hours at the same minimum temperatures. But the different amounts of killing in different localities during cold winters cannot be explained by differences in the mean temperatures, and can often be explained by differences in the temperature in some single night. Thus, during the winter of 1917–18, fruit trees were killed in the region of Oswego and Ithaca, New York, much worse than in the region of Brockport or Appleton. The mean monthly temperature for December at Oswego was 18.0° F.; Ithaca, 18.8° F.; Brockport, 19.4° F.; Appleton, 16.9° F. For January it was, at Oswego, 14.0° F.; Ithaca, 14.4° F.; Brockport, 11.3° F.; Appleton, 14.9° F. For February it was, at Oswego, 20.4° F.; Ithaca, 24.4° F.; Brockport, 21.9° F.; Appleton, 23.6° F. These differences are not large, and from the standpoint of continuous cold weather, trees in all sections should have suffered to about the same degree. From the standpoint of the coldest night, however, there is more nearly agreement with the amount of injury suffered. Thus, listing the stations in the order of the amount of injury to fruit trees, the minimum temperature was for Oswego, –21° F.; Ithaca, –22° F.; Brockport, –11° F.; and Appleton, –9° F.

While it seems almost certain that with wood of equal resistance the amount of killing is determined by the temperature of a single cold night the amount of root killing under field conditions is certainly greatly influenced by the duration of the cold weather. A single cold night would influence the temperature of the roots much less than it would influence that of the top. And the injury to some tissues is greater the longer the exposure to a given injurious temperature. Carrick (963a) found greater injury to apple fruit tissue held at –6.6° C., six to twelve days than when held only four days, although the interior of the fruit reached the temperature of –6.6° C. in two days. However, this declining fruit tissue capable of only katabolic processes may be very different in its responses from fruit tree tissues. Further, the air temperature during a single very cold night is much lower than any that is ever sustained even during a day or two. It is doubtful if even with the ripe fruits long exposure to –4° C. would be as injurious as exposure to –6.6° C. only long enough for the interior to reach that temperature. In fact he found much more injury to fruits that were only nine hours in reaching a temperature of –6.6° C. than to fruits that were forty-eight hours in reaching that temperature. The latter fruit was exposed to freezing temperature slightly above –6.6° C. much longer than was the former. Certainly the influence of the length of exposure to temperatures near that which is injurious is small compared with the influence of the rate of temperature fall.

The effect of water loss from the tissue on the resistance to low temperature. The statement is often made that the amount of injury is greater in dry than in humid sections. If the killing results from an extremely low temperature on a single night it does not seem that the moisture in the air could influence it; for, probably at such low temperatures when nearly all of the moisture is frozen out, the air in most sections would be equally dry. Generally, in humid sections near large bodies of water, the temperature does not go so low in the cold night; and this probably accounts for the view that a dry air favors killing. In laboratory freezing a difference of a very few degrees in the minimum temperature reached may mean the difference between no injury and very severe injury. In the open, also, this is certainly true with peach buds; and it seems probable that it is true with other tissues. It is idle, then, to draw conclusions as to killing in different sections unless the minimum temperatures reached are the same.

What evidence we have indicates that woody tissues will withstand lower temperatures if they are partly dried before being frozen. With seeds it is rather well known that dryness greatly increases resistance to low temperature. Thus, Schaffnit (1135) found no injury to dry wheat grains by a temperature of −18° to −22° C. for six to eight hours, though, of grains soaked in water for eight hours before being frozen, sixty per cent failed to germinate. Browne and Escombe (960) report the freezing of air dry seeds, of species representing the orders Gramineæ, Cucurbiteæ, Leguminosæ, Geraniaceæ, Compositæ, Convolvulaceæ and Liliaceæ, in liquid air in a temperature of −183° to −192° C. for one hundred and ten hours. These seeds did not have their germinating power appreciably reduced. Thiselton-Dyer (1148) reports seeds of mustard, peas, vegetable marrow, wheat, and barley all germinating after having been exposed for six hours to the temperature of liquid hydrogen, −250° to −252° C. Knowlton (1048) reports an interesting study with the pollen of the snapdragon and that of maize. Snapdragon pollen was found to contain from ten to twenty per cent of water; and it withstood the temperature of liquid air (−180° C.) showing sixty per cent of germination afterward. That of maize was found to contain fifty to eighty per cent of water and was killed at a temperature of −17° C. Higher temperatures that were yet below the freezing point were not used; and so it is not certain what temperature between 0 and −17° C. would kill it. It is certain, however, that it is much less resistant than that of the snapdragon with its lower water content. At the University of Missouri (967) dried pollen exposed to a temperature of −13° C. showed as little injury as turgid pollen showed following exposure to a temperature of −3° C.; and peach buds on trees that were cut down in the fall, or that were ringed through the sapwood in early winter, were more resistant to freezing than buds on normal trees of the same variety.

There was slow wilting of the wood and probably of the buds of the trees that had the water supply from the roots shut off. This slow wilting might be expected gradually to bring about changes in the protoplasm that would render it more resistant. However, more rapid loss of water also increases resistance. Thus, at the University of Missouri (967) seedling apple roots dried in the air at room temperature for eighteen hours were uninjured by a temperature that killed most of the tissue of turgid roots. Carrick (963) and Potter (1115) found similar results with larger numbers of roots. Getting the water out of the tissue then seems to increase its resistance to low temperature; and it is doubtful if evaporation from the twigs ever increases the amount of actual freezing to death.

Tissues may be killed in winter, however, not by freezing to death but by drying to death. If the roots are frozen during long periods and water from the soil cannot replace that lost by evaporation from the twigs, unless there is a very large reserve in the trunks or branches made available by brief periods when the wood is thawed, the twigs may eventually dry to death. Such drying to death, however, would not be determined by the temperature in a single cold night. In fact, if the tissues were badly dried but alive it is probable that their resistance to such a cold night would be greater than if fully turgid. Drying to death, it would seem, would be determined by the length of the period during which the soil was frozen and by the conditions for evaporation such as the amount of sunshine. Emerson in some unpublished work found the killing of raspberries in Nebraska, often at least if not always, to be a drying to death. Thus, when he coated the canes with paraffin they survived winters that killed uncovered canes. Such a covering would tend to protect from freezing to death succulent tissue that kills at but a few degrees below the freezing point of water. It does not seem, however, that it could protect such resistant winter tissue from direct freezing to death. That it should protect it from drying to death is evident.

It seems probable that water loss from twigs may be greatest in sections where the air is very dry, particularly during the brief time when it is above the freezing point; and that the next most important influence may be the amount and clearness of the sunshine. For, in winter, the more nearly direct the sunlight, the more the temperature of the twigs will be above that of the air and the greater will be the excess of the vapor pressure within the twigs above that of the air. The greater the excess of vapor pressure, the greater will be the movement of moisture out of the twigs.

Probably one of the strongest arguments for the view that dryness favors freezing to death is that in cold, dry climates, such as the Dakotas and Manitoba, dense windbreaks of evergreens often keep the trees from dying. It seems probable that in such sections, by deflecting the very dry winds the evergreens prevent drying to death. They also prevent the cold winds from taking heat away from the soil so rapidly, and thus reduce the amount of root freezing.

Closely related to the question of water loss from the tissue is the condition of the surface of the tissue. When freezing weather at blooming time is accompanied with snow and immediately preceded by rain it is often found that the leaves or the opening buds to the windward side of the trees are injured worse than those on the other side that were not so wet. Occasionally freezing temperature accompanied by snow has occured after fruits have set. The injury then is likely to be worse on the side of the fruit to which the snow adheres; and the fruit on the windward side of the tree is likely to suffer the greater injury. West and Edlefsen (1162) observed, following a freeze accompanied by snow and sleet, that blossoms which hung downward and did not collect ice were uninjured, while those which were upright and were filled with ice or snow were killed. In freezing green leaves at the University of Missouri, it was observed that leaves with dry surfaces and leaves dipped in liquid vaseline seemed to be more resistant than leaves with moist surfaces. Harvey (1022, 1023) has found that the waxy covering of certain leaves is at least a temporary protection against freezing. An interesting example of increased injury due to wet surfaces is furnished by West and Edlefsen (1162). These workers during a cold night sprayed water above each tree in an acre of apricots. Water collected and froze on the surface of the blossoms. They found all of the blossoms on these trees killed while those on adjacent, unsprayed trees were uninjured. It seems certain, then, that with tender succulent tissue, if the surface is wet the tissue is less resistant to low temperature. As to whether or not this would be true with winter dormant tissues, we cannot be certain, but it seems probable that it would not.

The effect of the rate of temperature fall on the amount of killing at a given temperature. Until recent years it was assumed that the rate of temperature fall has little to do with the amount of injury by low temperature. Pfeffer (1108) says that resistant plants withstand rapid and slow cooling equally well. However, later, Winkler (1173) working with Pfeffer, found a very marked difference in results when the twigs were cooled rapidly or slowly. Twigs that were killed at a temperature of –22° C., with rapid cooling were not killed at a temperature of –32° C., when the cooling required about fourteen days. At the University of Missouri

(967) it was found with peach buds as well as with other tree tissues that the rate of temperature fall is a very important feature in determining the amount of injury to winter buds and wood by a given low temperature. Peach buds cooled as rapidly as possible, requiring about ninety minutes to reach −17.7° C., had ninety-seven to one hundred per cent killed, while the same kind of buds in the same conditions cooling slowly, requiring about nine hours to reach −19.5° C., had only fifteen to twenty-eight per cent killed. Similar differences were noted in freezing the twigs of peaches, apples, cherries, and plums, and other wood of the apple.

There was apparently more injury when the rapid temperature fall was near the top of the scale, let us say from zero to −12° C., than when it was in the lower half of the freezing period, from −12° to −20° C. or lower. More data might be necessary, however, before one would be justified in concluding positively that this was true. Potter (1115) found with apple seedling roots that a very rapid temperature fall caused more injury to roots than was caused by a slow fall to the same temperature, though there was little difference unless the fall was extremely rapid.

This effect of rapid temperature fall is of considerable practical importance. It seems to explain the differences in the killing temperature of fully dormant peach buds. Generally, the buds will be killed if the temperature falls from near the freezing point to −12° or −14° F. in one night. Yet buds have survived a temperature as low as −25° F. No example of such resistance by peach buds has come to my attention in which the low temperature did not follow a period of considerable length during which the tissues were not thawed, day or night. Apparently the buds will be killed at an appreciably higher temperature in a sudden cold period. We have seen that this effect of rapid temperature fall seems to be the only means of explaining winter sun scald. It may influence the killing of twigs, spurs, buds, and other parts of the tree. Thus, twigs on the southwest side of the tree will not have shadows thrown upon them during any part of the afternoon, and with direct sunlight continuously they will be warmed up in the afternoon as with the trunk or large branches, and will suffer rapid temperature fall about sunset. Müller-Thurgau (1088) cites instances when parts on the south or southwest side were killed the worst; and in the Cornell Experiment Station orchard during the winter of 1917–18, nearly every apple tree that was injured at all showed more injury to spur, twig or branch on the south or southwest side than elsewhere. Müller-Thurgau thinks that such results as these and sun scald occur because the tissue on the southwest side is started into initial stages of growth by the higher temperatures which they often endure. We have seen that this can hardly be true of sun scald, and it certainly was not true in the Cornell Experiment Station orchard in 1917–18; for in that year the killing probably all occurred on the night of December 30th, when the trees were still in their rest periods, and when the temperature during the preceding winter days had been continuously low. However, when the killing is in late winter the buds and possibly the twigs may sometimes be injured worse on the south side of the tree for the reason suggested by Müller-Thurgau.

It should be said that, while the rate of temperature fall is often of determining importance with dormant tissue, which withstands rather low temperature, and with ripe apple tissue (Carrick, 963a), it was not possible at the University of Missouri to influence the amount of killing of tender succulent tissues such as blossoms and young fruits, by varying the rate of temperature fall. This problem will be discussed in more detail in Chapter 22.

The effect of the rate of thawing on the amount of injury by low temperature. It is very common, in popular literature, to find the statement made that the injury resulting from freezing is generally caused by a rapid thawing. This opinion has long been held by the uninformed and was at one time held by informed scientists. Yet Goeppert (1004) concluded from many experiments that the rate of thawing does not influence the amount of killing. Sachs (1132) thought he found that the injury is entirely due to the rapid thawing. One of the methods followed by Sachs was to freeze pieces of pumpkin and sugar beets immersed in water. On thawing, it was found that only the part above the water was killed. Sachs concluded that the part below the water was uninjured because of the slow thawing. Molisch (1086) from experience with plant stems partly immersed in water that was frozen, reached the same conclusion. However, both he and Müller-Thurgau (1088) found later that the part beneath the water had really never been at the freezing point of the tissues; the ice not having been below zero centigrade while the freezing point of the tissues was at least about one degree below zero.

Sachs thought also that he prevented injury to frozen tissues by thawing them slowly in water near the freezing point. Müller-Thurgau pointed out that if Sachs saved the tissues in this way, it was not by slow thawing, but was in fact by very rapid thawing. On immersion in the cold water a film of ice would form around the tissues and the latent heat released by ice formation would be enough very quickly to thaw the tissues within. In actual studies ice crystals disappeared more quickly from tissue thawed in this way than from tissue thawed in air at higher temperatures. With apples having thermometer bulbs imbedded in the tissue the rise in temperature was more rapid in water at 0° C. than in air at

5.2° to 5.5° C. Both Müller-Thurgau and Molisch (1086) studied the effects on frozen tissue of slow and rapid thawing and found, with nearly all tissues studied, that the rate of thawing exerted no influence whatever on the amount of injury at a given temperature. At the University of Missouri (967) tissue of a considerable number of different kinds of succulent species; the fruit buds, the flowers and the young fruits of several varieties of peaches; the young fruits of the apple, the pear, the peach, and the plum; and ripe fruits of the peach, the plum, and the apple were frozen at temperatures that would cause some injury to the tissue. With each lot half of the numbers used were taken out of the freezer and thawed in a warm room and half left in the freezer which was so adjusted that the temperature would rise very slowly. With every kind of tissue used, except lettuce leaves and the ripe fruits of the apple and the pear, there was caused by the rate of thawing no perceptible difference in the amount of injury by a given temperature. Carrick (963) and Potter (1115) found with apple seedling roots no appreciable influence of the rate of thawing on the amount of injury resulting from exposure to temperatures low enough to cause some injury.

Müller-Thurgau and Molisch found with ripe apples and ripe pears that thawing rapidly, in water or in air, rather markedly increased the amount of injury by the temperature that first begins to kill; but exposing the tissues to a temperature somewhat lower killed regardless of the rate of thawing. In other words, even with ripe apples and pears, the rate of thawing is only an influence and not the only cause of the injury. Carrick (963a) found thawing ripe apples in water greatly to increase the amount of injury from exposure to a given temperature; but he did not find the amount of injury even to ripe apples greater with rapid thawing in air than with slow thawing, provided the fruit was not handled in either case. The injury to frozen apples is increased by handling. Thus when unmolested fruits are killed to depths of one fourth of an inch, the killing may extend to the core at points where the fruits, while frozen, were pressed with the fingers.

Molisch found leaves of *Agave americana* injured by rapid thawing, and Dorsey and Strausbaugh (988) seemed to find greater injury to flower buds of some plum varieties when twigs were cut from the trees and taken at once from a temperature of −18° F. into a warm greenhouse at a temperature of 80° F., than with buds of the same varieties when the twigs were kept two hours at −4° F., two hours at 13° F., and two hours at 35° F. before being placed in the greenhouse room at 80° F. Such very rapid thawing might cause injury by causing changes that would not result under the most rapid thawing possible in a natural environment.

Perhaps with none of the tissue studied are we justified in concluding unreservedly that the rate of thawing exerts no influence whatever on the amount of injury from freezing; but we are certain that any such influence is too small to be of any importance. However, with a few tissues it seems to have an influence that is of some importance. Each different kind of plant or plant tissue seems to present a separate problem as to whether or not, with it, there may be a slight influence of the rate of thawing on the amount of injury from exposure to low temperatures that kill only a part of the tissue. However, with all tissues containing some water, a temperature may be reached at which it is killed regardless of the rate of thawing; and with none, at any temperature, does the rate of thawing seem to be a major influence as to the amount of killing.

The effect of sunlight on frozen tissue. The statement is often made that parts of an orchard protected from the early morning sun show less injury following a freezing night temperature than is shown in other parts. In California, it is often said that following a night of a freeze the injury to fruits of Citrus and of the olive is greater on the south side of the tree. O. Gara (unpublished) reports having saved fruit blossoms by spraying them with water early in the morning. Of course, if he saved them by this method it was not by a method of slow thawing since they would thaw more rapidly under the effects even of cold water than by the ordinary rising temperature as the sun comes up. When plants are frozen in greenhouses or in houses, it is a common practice to thaw them by spraying them with cold water. It is assumed that they are thus being thawed slowly, though as a matter of fact, they are being thawed instantly. Müller-Thurgau (1088) indicates that at one time the opinion, that such spraying of frozen plants is beneficial, was as general among growers of trees as it is now among growers of plants under glass. If the practice is ever beneficial, it may be that the rapid (almost instantaneous) thawing prevents injury from sunlight on frozen tissue. It is conceivable that injurious chemical changes might be caused by the sun's rays when the tissue is frozen; though there is little or no evidence that such injury ever occurs; and some evidence indicates that it does not.

Müller-Thurgau, from much observation in a vineyard region, where the leaves were often killed by freezing, could find few leaves on vines protected from the morning sun to suffer less injury than exposed leaves suffered. We often see blossoms of fruit trees withstand surprisingly low temperatures when the sun shines intensely upon them before they are thawed. Thus, at Ithaca, New York, on the night of April 11, 1921, the temperature was at 22° F. from 2 A.M. to 6 A.M. and was 27° F. at 7 A.M. long after sunrise. The sun shone very clearly in the morning following the freeze; yet peach blossoms nearly open and apricot blossoms past full bloom were uninjured. This is generally a killing temperature for such blossoms; and we can be reasonably certain that if the temperature had gone a degree or two lower nearly all would have been killed. The injury from this sunlight must have been exceedingly small if there was any. Better evidence was furnished on May 17, 1921, when all the leaves and young fruits in the Cornell University orchard were frozen stiff and much of the fruit was killed. The season was an early one and the foliage had become very dense. It is certain that the fruits on the east and northeast side of a tree were in the sunlight before those on the other part of the tree. Yet examination of more than a thousand trees indicated that with none of the deciduous fruits was there a tendency for the killing to be worse on the side that received direct sunlight before thawing. This certainly suggests that with deciduous fruits, sunlight is seldom or never injurious to the tissue while frozen; and there is no proof that it is injurious to other fruits or to plants in the greenhouse. With Citrus and olive trees, which have dense foliage, it would be expected that the killing would be worse on the side away from the wind (if there were a slight wind during the cold night). For on the windward side there would be slight moving of the fruits and foliage and thus a tendency to bring them in contact with air that had not been cooled by contact with the fruit and leaves. These, because of radiation from their surface, would, in a rather still night, tend to be at a temperature a little below that of the air.

Spraying plants in the greenhouse with water before the temperature begins to rise might save them by preventing the temperature from going as low as it otherwise would; but I know of no evidence that spraying after sunrise, or after the minimum temperature has been reached, does any good. Naturally, if there is some freezing in the greenhouse, though not enough to injure the plants, the grower, if he sprays them and leaves no checks, will assume that he saved them. Spraying in the greenhouse will generally do no harm, since, because of the heat from the water, there is little danger that the temperature will again go low enough to freeze the wet plants. With fruits in the orchard, however, spraying in a cold night is dangerous; for West and Edlefson (1162) found that if the wet surfaced tissue freezes again it may be injured worse than if no water had been sprayed onto it.

Harvey (1022, 1023) has suggested another reason why spraying frozen plants might be beneficial. He found with cabbage plants that where small areas of tissue are killed, injurious substances cause the growth of tumors on the leaves. If the leaves were dipped in water, these tumors did not form. Spraying to prevent the formation of such would be beneficial only on leaves with such killed areas; and so if upon thawing the tissues were found entirely uninjured, a person could be certain that his spraying had not been necessary. There would have been no injurious substance. Of course, it is probable that with tissues of fruit trees such tumors would not form at killed areas.

While what evidence we have suggests that sunlight is not injurious to frozen leaves, blossoms, fruits, and other tissues of deciduous fruit trees, we would hardly be justified in concluding that it may not be slightly injurious to tissue of some kinds of plants.

Summary. When the wood is well hardened, pith is generally the least resistant tissue, sapwood next, bark next, and cambium most; though, when it is not well hardened, cambium may have as little resistance as any. Dead areas, known as "crown rot" in the trunks of trees may be due, at times, to other agencies, but are often due to freezing; the tissue near the base of the trunk being slow in reaching greatest resistance. Such injury on the southwest side of the trunk, often called "sun scald," may be increased by the very rapid temperature fall that results when the sun rays cease to strike tissue that, in late afternoon, has been warmed by the direct rays. The tissue in the crotches formed by upright crowding branches is slow in acquiring normal winter resistance to freezing and large wounds may be formed which are very slow in being covered by callus. Branches with such wounds should generally be braced in the first summer after the injury. With wounds caused by freezing, the bark should generally be left over the wound one year, or at least until late in the summer after the injury, in order to be certain that no live cambium is removed.

Vegetative buds are generally more resistant to freezing than fruit buds; but when the tree goes into winter in a very immature condition, these buds may be killed when fruit buds and other tissues are not killed. There is much loss from the freezing of fruit buds. With some kinds the buds are much less resistant if flower part differentiation has reached an advanced stage at the beginning of winter. On rather strongly vegetative trees differentiation is less advanced than on less vigorous trees. With some kinds the rest period, by inhibiting response to temperatures favorable for growth, may, in late winter, prevent the buds from losing resistance; but there is no conclusive evidence that the kinds most resistant while fully dormant have the longest rest period, or that, after the ending of the rest period, the tissue becomes less resistant before there is warm weather to start growth. The scales on the buds protect them from water loss but do not increase their resistance to low temperature. Usually, in the development of the buds into blossoms and in the development of the young fruit, there is a continuous decline in resistance; but, under some conditions with apples and cherries, at least, there may be stages preceding full bloom when the resistance is no greater than that of open flowers.

The nearly ripe fruit of some kinds, such as the peach and the Labrusca grape, has very little resistance to freezing; while that of some varieties of apples and pears is considerably more resistant.

As normally grown, the roots are in winter much less resistant to freezing than are the parts above ground. Root tissue that is uncovered during the summer may become nearly as resistant as other wood.

The most important feature in determining the resistance to freezing is the maturing or hardening of the tissue that proceeds during late summer, autumn and early winter. We do not know what the changes in the tissue may be, but they are apparently dependent upon a large supply of carbohydrates. At latitudes below 43° to 45°, medium early cessation of growth, rather than very early or very late, contributes to the most satisfactory hardening; at higher latitudes, earlier cessation may be desirable, and at lower latitudes later.

While we do not have enough experimental evidence, it seems reasonably certain that beyond a few hours, the length of exposure to the minimum temperature is not very important, and that injury in an orchard usually occurs in a single night.

Succulent growing parts, such as leaves or blossoms, are killed by a higher temperature if the surfaces are wet than if they are dry. Wilting the tissue increases its resistance to low temperature; and it does not seem probable that the nature of the atmosphere influences the amount of injury caused by a given winter temperature. However, when the roots are frozen, during long periods, and cannot supply water to the top there may be drying to death.

With winter dormant tissue the rate of temperature fall is very important in determining the amount of injury from exposure to a given low temperature; though, with growing succulent tissue this does not seem to be true.

With most plants studied, the rapidity of thawing has no measurable influence on the injury from exposure to a given temperature. With some tissues it seems to have a slight influence. Thawing ripe apples or pears in water greatly increases the injury.

There is no evidence that direct sunlight injures frozen tissue; though, perhaps, the evidence is not conclusive that it does not cause some slight injury.

CHAPTER 22

EVIDENCE AS TO HOW FREEZING KILLS

A VERY large amount of study has been devoted to the problem as to how freezing kills plant tissue. The problem is one that appeals to the student of general plant responses. It will be of interest to students in pomology if results are obtained which suggest or explain practices that may be of assistance to the grower in reducing the amount of injury to his orchard caused by freezing. Since, in popular literature concerning freezing injury in orchards, advice to growers is often based upon erroneous notions or inconclusive evidence as to how freezing kills, it seems well briefly to discuss the condition of our knowledge concerning this subject.

Tissue killed by freezing has a different appearance from that killed in some other ways. Wood that has been dried to death continues to be light in color, while wood frozen to death assumes a brown water-soaked appearance. Wood killed by heat, however, has the same brown watery appearance; in fact, any sudden or rapid killing of the wood may be expected to result in this brown appearance. It is well known that plants not in the resting stage may be killed by long exposure to temperature slightly above the freezing point. This is a different phenomenon from direct freezing to death, as Molisch (1086) has indicated. At such temperatures the leaves may turn yellow and fall and the tissue dies gradually, never having the brown water-soaked appearance of tissue frozen to death. Goeppert (1004) has emphasized the fact that tissue frozen to death has a greatly reduced ability to hold water; evaporation from frozen tissue being much more rapid than from living tissue. Probably tissue killed by heat or by organisms, such as that causing pear blight, would have its water-holding power similarly reduced. I do not know whether or not drying to death has such a marked effect on the water-holding power of the tissue; but it seems probable that at least with some tissues, such as fruits, it has not. We have seen in the previous chapter that freezing to death seems to reduce the breaking or splitting strength of wood much more than does drying to death. In other words, killing by heat or by freezing seems to cause a more complete disorganization of the protoplasm and perhaps of some substances in the cell wall, than does drying to death; and possibly more than does killing by some other means. Dorsey and Strausbaugh (988) found that, in cells of flower buds of the plum that have been killed by freezing, the plasma membrane and the nuclear membrane no longer appear as distinct limiting membranes. The outline of the nucleus is lost, there being merely a dense smutch of stain in the position normally occupied by the nucleus. Yet with the methods of staining used the plasma membrane and the nuclear membrane showed very distinctly in unfrozen cells. These unfrozen cells also had been killed, but by laboratory reagents. While the colloidal nature of the protoplasm was probably changed there was not disorganization such as freezing causes. In this chapter, we are not concerned with secondary effects of low winter temperature (such as drying to death during a period when the roots are unable to supply water to the soil); but only with direct freezing to death that is characterized by such complete disorganization of the protoplasm.

Before tissue will freeze to death ice must be formed in it; at least this is true of succulent tissues that are killed at not many degrees below the freezing point of water. Thus, tissue that is frozen under conditions where it is kept very still may be supercooled; that is, cooled to a temperature below its freezing point without ice formation. Both Müller-Thurgau (1088) and Voigtlander (1154) found that tissue may be cooled to a temperature well below that at which it ordinarily kills; and, if it can be warmed back without ice formation, no injury results. Of course, with tissues such as winter wood or buds that require temperatures as low as −30° F. to kill them, ice formation will generally occur long before the killing temperature is reached. Dorsey and Strausbaugh found that with some plum species, while there was ice formation among the scales surrounding them, there was apparently no ice in flower buds of the plum at a temperature of −21° F. However, since ice in the scales would serve for inoculation when the freezing temperature of the flower buds was reached, supercooling would not be possible. We could not learn from experience, therefore, whether or not ice formation is necessary for the freezing to death of such hardy tissues, for we could not get them to killing temperatures without ice formation. Johnston (1042) found ice formation in peach buds at 17.6° to 19.4° F.; but he did not determine whether the ice was among the scales, in the tissue of the flower parts, or in adjacent tissue.

Many workers, including Sachs (1132), Müller-Thurgau, and Molisch (1086) have studied the formation of ice in the tissue. The first two workers seemed to find ice very seldom formed within the cells. Unless the temperature fall was very rapid, ice was found in the intercellular spaces. Molisch found cells of some plants to freeze solidly by the formation of ice in the protoplasm, others to have the ice formed only outside of the cell, and others to have the ice formed both around and within the cell. Wiegand (1169) studied the formation of ice in the winter twigs and buds of woody species and found that with these tissues generally, the ice is formed in intercellular spaces, though in both organs the ice was sometimes found in cells. According to this worker the ice was found always in broad prismatic crystals arranged perpendicular to the surface from which the water was withdrawn. If water was supplied from both sides of the sheet of ice there was a double layer of these crystals. With such winter twigs at temperatures of −25° to −18° C. the cells from which the water was withdrawn were compressed and distorted, but upon thawing were found to be uninjured.

Greeley (1012) found the water largely extruded from Spirogyra cells by exposure to a temperature of 1° to 2° C.; and Pantanelli (1106) found, with segments of Mandarin orange pulp, that, at temperatures near the freezing point (−5.5° C., in this case the freezing point being at −6° C.) water was extruded from the cell. As to whether or not it is generally true that, at the temperature at which freezing begins, a large percentage of the water has been extruded into the intercellular spaces, we cannot say with certainty; certainly much of it is in those spaces soon after ice formation begins. Müller-Thurgau (1088) has emphasized the fact that the ice formation is very rapid at first. The tissue is generally cooled to several degrees below the freezing point before ice formation begins, and then the temperature rises at once to near the actual freezing point. This rapid rise in temperature is made possible by the heat liberated in ice formation. If the supercooling represents a considerable number of degrees, large amounts of ice must be formed very quickly; as the amount of heat released indicates. Müller-Thurgau observed ice formation so rapid that the heat liberated in a small piece of tissue was enough to raise the temperature of the tissue and of the glass and mercury of a mercury thermometer 4.5° C. in one minute.

When the tissue is at the freezing point or below, ice crystals do not begin to form at all points at the same time. Rather, according to Müller-Thurgau and others, there are points where crystallization begins and the water in adjoining or even somewhat distant intercellular spaces moves to these crystallization centers. The ice masses are largest at these first inoculation points. Müller-Thurgau separated these ice masses from the tissue, evaporated them to dryness, and found them composed of nearly pure water. This would be expected, since when any water solution freezes the first ice is from pure water, unless there is in solution something that crystallizes at a temperature nearly as high as the freezing point of water. As the water freezes out, the unfrozen sap will be left more concentrated. Then before more ice will be formed, the temperature must go lower. When the crystallizing temperature (eutectic point) of any material is reached, more water will be released to form ice. With many substances crystallization proceeds rather slowly. The water will then be as slowly released for ice formation. Until the eutectic point of all material in solution is reached some water in the vacuoles will remain unfrozen.

Water will be held, also, by the protoplasm itself and by the cell walls. More of this will be frozen out as the temperature goes lower. The imbibitional holding of the water in the protoplasm and cell walls; the osmotic pressure holding water in the vacuoles, or as films in contact with protoplasmic surfaces; and the tendency of the water to crystallize will approach equilibrium. If the temperature should fall lower than the eutectic points of all materials in solution, there would be equilibrium between ice formation and imbibition in the tissue. An osmotic pressure of about 360 atmospheres would prevent ice formation at −22° F. Shull (518) seemed to find that a considerable amount of water may be held much more strongly by imbibition. The water is, of course, held less strongly the nearer the moisture content approaches saturation. In air dry *Xanthium* seeds the imbibitional pull seemed to be about 965 atmospheres. More water is held by imbibition in some tissues than in others. Hooker (1033), Rosa (1127), and Newton (1092a) have shown that the pentosans are very important colloidal materials in holding water against ice formation or transpiration. These may be found both in the cell walls and in the protoplasm; and the hardening process by which tissue becomes more resistant to freezing is, at least with some plants, associated with a large accumulation of pentosans and related colloidal carbohydrate compounds.

There are at least three ways in which freezing might be expected to injure the protoplasm.

First, as the temperature falls and the water is frozen the protoplasm is left increasingly dryer.

Second, with lowering of the temperature the eutectic point of some of the substances in solution is reached. As these go out of solution the reaction and composition of the liquid in contact with the protoplasm is changed and this might profoundly influence the nature of the protoplasm. Thus, Harvey (1022) seems to find, with cabbage, that as it freezes the acidity increases much more rapidly than the concentration of the sap increases.

Third, with the lowering of the temperature, the ice mass becomes larger and more rigid and presses more closely against the protoplasm, if crystals do not actually penetrate or form within the protoplasm.

In considering the different theories that have been proposed to explain freezing to death, only those that might explain it as an irreversible change in the structure of the protoplasm need be considered. Du Hamel and Buffon (989) thought that injury was due to rupture of the cell walls by the expansion of the water upon freezing within the cells. We have seen that most of the ice seems to be outside of the cells. Further, even if the cell walls were ruptured the injury would probably be repaired if the protoplasm were uninjured. And Nageli (1090a) showed that the expansion of the water in the cell would not be great enough to rupture the wall. Goeppert (1004) and Müller-Thurgau (1088) found that, even when ice masses within the tissue become so large that the cells are torn away from each other and the tissue pressed far out of its natural form, the cells that have been torn from each other may not have been killed.

Withdrawal of water from the cells during freezing. Until recently students of the phenomenon of freezing to death were inclined to think of it as an irreversible change in the protoplasm due directly to the withdrawal of water to form ice. It is not known what amount of water loss many kinds of plant tissue may withstand. Pfeffer (1108) says that very sensitive succulent tissues may withstand a loss of forty to fifty per cent of their water, and vegetative organs of some flowering plants may withstand a loss of eighty to ninety per cent of their water. How nearly universal such resistance to drying may be we do not know. In freezing, however, even larger percentages than these may be in the form of ice, and therefore, lost to the protoplasm. Thus, Müller-Thurgau, by methods that seem reasonably accurate, determined that with pieces of apple fruit at −4.5° C., 63.8 per cent; at −8° C., 72.4 per cent; and at −15.2° C., 79.3 per cent of the water was in the form of ice. By using a method that may be less dependable he seemed to find, with a piece of oak twig, that at −20° C., 76 per cent of the water was in the form of ice. It seems certain, therefore, that, at temperatures which kill the tissue, the protoplasm may be deprived of water to an extent that would kill it at temperatures above the freezing point. We should expect, however, that at low temperatures, at which chemical changes proceed very slowly, much greater drying might be required to kill the protoplasm than would be required at growing temperatures.

Müller-Thurgau thinks death by freezing is due directly to the rapid loss of water from the protoplasm, this rapid loss causing a disarrangement of the small particles of which the protoplasm is composed. Succulent tissues are generally killed at higher temperatures than others, because the particles "mycelles" are farther apart and more easily disarranged by rapid loss of water. He admits, however, that some very succulent tissues are relatively resistant to freezing.

Considerable numbers of rather conclusive experiments have shown that increasing the amount of material in solution will increase the resistance to low temperature of tissue not in a dormant condition, provided the substance is not very toxic and stays in solution at the temperatures involved. Since this material will keep water unfrozen, the fact that it tends to lower the killing temperature may be considered as evidence in favor of the view that death results directly from the withdrawal of water from the protoplasm. However, if this material holds, unfrozen, water that would not be held by the protoplasm, it must be because it has greater attraction for the water than the protoplasm has. The water, it would seem, would be held by the material and not by the protoplasm, and the water supply to the protoplasm would not be increased.

Hooker (1033) has found a greater pentosan content in mature than in immature wood, and Rosa (1126, 1127) has found that the pentosan content of hardened vegetables is greater than that of the same kinds unhardened. These authors think that the pentosans in the protoplasm increase its resistance to freezing by increasing its ability to hold water by colloidal absorption. And Newton (1092a) seemed to find that the tissue of hardened wheat is rather rich in such colloidal substances as pentosans and shows much greater resistance to low temperature, and holds water more strongly against evaporation and against pressure than does unhardened tissue.

However, even though increased quantities of such colloidal substances as pentosans in the protoplasm increases its resistance to water loss and also its resistance to freezing, it does not, necessarily, follow that killing by low temperature is due merely to desiccation of the protoplasm. By preventing water from being frozen it may prevent injurious concentration of substances in the cell solution; or by preventing the ice mass from becoming so large it might conceivably prevent mechanical injury to the protoplasm. It seems to me, however, that the most plausible explanation of the protective effect of very stable colloidal substances, such as pentosans, is that they increase the stability of the protoplasm against irreversible changes, such as coagulation or disorganization, whether caused by freezing or in other ways. Thus, McDougal and Working (1058) seem to think that pentosans in the protoplasm of Opuntia may account, in part, for its great resistance to high temperature.

There is some evidence that does not seem to harmonize well with the theory that death from freezing is due directly to water withdrawal from protoplasm. Thus, dry seed may withstand the temperature of liquid hydrogen; but if considerable quantities of water are absorbed even rapidly they may be killed at rather high temperatures. Yet seeds that have absorbed water may be dried again without injury. In other words, moist seeds are not affected alike by freezing and drying, though it would seem that they should be if death from freezing were due merely to water loss from the protoplasm. With at least some colloids, the effect of freezing is different from the effect of drying. Thus, starch paste is not irreversibly changed by drying, but is by freezing.

A modification of this theory is that death may not result directly from the loss of water from the protoplasm, but that the withdrawal to form ice results in chemical changes that cause the death of the protoplasm. Molisch (1086) while adhering to the theory of Müller-Thurgau, rather freely interpreted, says, "It must, however, be emphasized that other means of damaging are not excluded. Thus, concentration of sap may play an important rôle, particularly since some dissolved substances may go out of solution. If a plant can endure only a certain degree of concentration of any soluble compound, as potassium oxalate, the danger increases with the concentration, especially as these may give rise to new reactions and compounds. Such changes, however, are only secondary effects of the water withdrawal to ice formation."

Concentration of or changes in the sap solutes. Gorke (1011) has suggested the theory that death of the protoplasm results from concentration of the sap in the same way that protein is precipitated from solution by concentration of salts. The proteins may be precipitated by freezing; and Gorke found that the proteins in the sap of the tender Begonia would be precipitated by a temperature as high as −3° C., while it required a temperature as low as −40° C. to precipitate the proteins from the sap of pine needles. Schaffnit (1135) found that the proteins of rye, grown under conditions such that it was very resistant to low temperature, were not precipitated at temperatures that would cause precipitation of the proteins from the sap of rye grown under conditions that cause it to be very tender. He found also that he could prevent the precipitation of proteins by the addition of small quantities of sugar. He is inclined to accept Gorke's theory, and thinks that the sugar in the sap tends to prevent precipitation of the proteins; or to prevent changes in the constitution of the protoplasm similar to the changes in the proteins when they are precipitated. He and Lidforss (1052) think that the starch of a hardy plant changes to sugar on the approach of winter and thus protects the protoplasm against changes similar to the precipitation of protein. We have seen, in Chapter 1, that fats are important winter storage materials;

and the quantity of fat rather than of sugar may be greatly increased with the disappearance of starch in autumn and winter. Dorsey and Strausbaugh found in the storage region (pith cells) of plum fruit buds mainly protein substances, fats and dextrin.

Harvey (1022) thinks that, in frozen tissue, the proteins of the sap and probably of the protoplasm may be irreversibly changed through the increased acidity of the sap. He found the acidity in cabbage leaves to increase during freezing much more rapidly than the total concentration of the sap increased. In other words, the increase in acidity was greater than would be caused by the withdrawal of water to form ice. He suggests that the increased acidity may be caused by some alkaline substance with a high eutectic point going into the solid phase. It was found, at the University of Missouri (967) that proteins were apparently precipitated from the sap of cabbage, kale, and lettuce by exposure to a temperature of −3° C., −6.2° C., and −5° C., respectively. There was some slight evidence also that larger percentages of the proteins were precipitated from the sap of tender greenhouse plants than from hardened plants that would not be killed by a temperature of −6° C. with cabbage; or of −5° C. with lettuce. The evidence strongly indicated that no proteins were precipitated from the sap of twigs of apple, pear, peach, and plum by exposure to temperatures that would kill the twigs at that time (September and October). However, the fact that there were no easily precipitated proteins in the sap of these twigs does not necessarily argue against the theory of Gorke or that of Harvey. There might have been, in the protoplasm, compounds that are irreversibly changed by the concentration of some substance in the sap.

Harvey found that a smaller percentage of the protein was precipitated from the sap of hardened than from that of tender cabbage plants by freezing at −4° C. for two hours. Further, when sap of the hardened cabbage plants was treated with sulphuric acid a smaller percentage of the protein was precipitated than from the sap of tender cabbage plants receiving the same treatment. It seems probable that, as the temperature falls and the eutectic point of some substances is reached, the solution left may be injurious to the protoplasm. Antagonistic action between chemical substances in their influence upon protoplasm is well established. For example, in the presence of calcium chloride, sodium chloride is less injurious. It does not seem improbable that substances that protect the protoplasm against the injurious action of other substances might go out of solution at low temperatures, and that injury to the tissue might result.

It should be emphasized, however, that concentration of the hydrogen-ion or of other ions that would injure protoplasm at normal temperatures, might not cause such injury at freezing temperatures. For, at lower temperatures, chemical action tends to be slower. The results of Maximow (1073, 1074) seem difficult to harmonize with the theory of Gorke. Maximow worked with thin razor sections from the upper side of the leaf of red cabbage and of *Tradescantia discolor*. These were frozen in pure water and in solutions varying in concentration from one sixteenth normal to twice normal. The sections used were so thin that probably nearly all the cells were in contact with the solutions in which they were frozen. (In thicker sections or with whole leaves the solution would probably influence the reaction of only the surface cells with which it could come in contact.) If the theory of Gorke, Schaffnit and Lidforss were correct, such thin sections frozen in solutions of a substance like glucose, which protects against salting out of proteins, should withstand a lower temperature than when frozen in water. When frozen in a solution of a salt that precipitates proteins they should be killed at a higher temperature than when frozen in water. Further, when frozen in solutions of substance that neither salt out proteins nor protect against salting, the killing should be the same as when frozen in pure water.

In Table 66 is shown the maximum strength of some of the substances used by Maximow and the minimum temperatures withstood.

The solutions of electrolytes were iso-osmotic with normal solutions of non-electrolytes, rather than being actually normal solutions as indicated in the table. At first the pieces of tissue were left in the solution for several hours in order that the material might penetrate the protoplasm. It was soon found, however, that as much protection was afforded when the sections were placed in the solutions and immediately frozen. Sugar showed no more protective action than a number of mineral substances showed. This experience makes it difficult to accept the view of Lidforss and Schaffnit that sugar has a peculiar protective action against killing by freezing, due to its influence in preventing the salting out of proteins.

It does not directly oppose the theory of Harvey that death results from an increase in the hydrogen-ion concentration; for the solutions were neutral or slightly alkaline. In fact, Maximow found that small concentrations of citric acid reduced the resistance of the tissue to low temperature. He does not say whether or not the tissue was frozen immediately upon being placed in the citric acid solution. If the tissues were in the acid media for a considerable time unfrozen, it seems possible that it might so change the nature of the protoplasm that it would be less stable. It might then be less resistant to freezing regardless of how freez-

TABLE 66. THE KILLING TEMPERATURE IN DEGREES CENTIGRADE OF THIN SECTIONS OF RED CABBAGE AND OF TRADESCANTIA IN VARIOUS SOLUTIONS

In What Frozen	Minimum Temperatures Withstood
Red Cabbage Leaf	
Pure water	− 5.8°
Glycerine, 2 n conc.	−22.0°
Glucose, 2 n conc.	−32.0°
Methyl alcohol, 2 n conc.	−11.1° to −17.3°
Ethyl alcohol, 2 n conc.	− 7.8° to −11.8°
Mannite, 1 n conc.	− 5.8° to − 7.8°
Sodium chloride, 2 n conc.	−32.0°
Potassium chloride, 2 n conc.	−11.1° to −17.3°
Calcium chloride, 2 n conc.	−22.0° to −32.0°
Sodium nitrate, 1 n conc.	−17.3°
Potassium nitrate, 1 n conc.	− 7.8°
Calcium nitrate, 1 n conc.	−17.3°
Sodium acetate, 2 n conc.	−32.0°
Potassium acetate, 2 n conc.	−32.0°
Calcium acetate, 2 n conc.	−17.3° to −22.0°
Sodium lactate, 2 n conc.	−32.0°
Potassium lactate, 2 n conc.	−32.0°
Sodium oxalate, 1 n conc.	− 5.8° to − 7.8°
Potassium oxalate, 1 n conc.	− 7.8° to −11.1°
Mannite and potassium nitrate, 1 n.	−11.1°
Expressed red cabbage sap	−11.1° to −17.3°
Expressed and boiled red cabbage sap	−11.1° to −17.3°
Tradescantia Discolor Leaf	
Pure water	− 1.0°
Glucose, 2 n conc.	−22.0° to −32.0°
Mannite, 1 n conc.	− 5.8° to − 7.8°
Sodium chloride, 1 n conc.	−11.1°
Expressed red cabbage sap	− 7.8°

ing causes disorganization of the protoplasm. If the effect of the citric acid were to make the protoplasm less stable before freezing began this experience of Maximow would furnish little proof that increasing the acidity of the protoplasm after it had reached a low temperature would be injurious. In fact, the work of Maximow offers convincing proof that the toxic action of a substance must be much reduced by low temperatures. For it must be considered that at some of the lower temperatures water had been frozen out and the tissue was in saturated solutions of the protective substances used. Certainly at temperatures above freezing, solutions less concentrated than saturated solutions of sodium nitrate or of potassium nitrate would kill the tissue. In fact, it is probable that, at temperatures above freezing, solutions of any of the substances named in Table 66 would kill the tissue, if the concentration was as high as it must have been with each of these after a considerable amount of the water had been frozen out. Yet, at temperatures below freezing such concentrations of these substances were apparently not injurious. Evidently at such temperatures high concentrations of some toxic substances may cause little injury.

One of Maximow's experiments seemed to yield results in conflict with the views of Harvey. When sections of the red cabbage leaves were frozen in the expressed sap of red cabbage some cells withstood a temperature as low as −17° C. Yet when frozen in pure water or as whole leaves in air, the cells were all killed by a temperature of −5.8° C.; and, unless the reaction of this sap was different from that used by Harvey, the hydrogen-ion concentration in the liquid surrounding the piece of tissue must have been much greater than in the sap used by Harvey. For at the higher temperatures used by Harvey less water would be frozen out. This suggests that the material in solution in the sap, instead of being harmful to the protoplasm, actually protects it against the effects of low temperature. The protecting effect of the red cabbage solution on Tradescantia cells was as striking, the Tradescantia cell in the red cabbage sap withstanding a temperature of −7.8° C., though in water it would be killed at −1° C.

Increase in the amount of ice and the rigidity of the ice mass as the temperature falls. While it seems to be true that the ice masses are generally in the intercellular spaces, it does not seem probable that in any of the microscopic studies of ice in plants the techinque was such that it could be determined with certainty whether or not ice crystals penetrated into the protoplasmic masses. In Amœba, Molisch found a network of ice. Most of the studies that have been made with fruit tree or other dormant woody tissues have been at temperatures considerably above that which would kill the tissues concerned. It does not seem impossible that after most of the water of the vacuoles has passed out of the cells to form ice, as the temperature continues to fall, very small ice masses may be formed throughout the protoplasm from the water of imbibition that is finally given up.

Even if no ice is formed within the protoplasmic mass, microscopic examination shows that the cells are strongly compressed by the ice masses outside. These masses grow larger and unite and the ice system in the tissue must become more rigid as the temperature becomes low enough to freeze the water of imbibition and nearly all, if not all, of the water held by the solute. (The eutectic point of much of the solute must be above the killing temperature of many kinds of dormant tissues.) It is known that grinding tissue with fine sand will cause the protoplasm to give up materials that are otherwise held. In other words, its semipermeable character is destroyed by this treatment. It seems possible that pressure caused by such growing ice masses on the component colloidal particles of the protoplasm may have the same effect.

Chambers (965) has studied the protoplasm of certain small animals by means of microdissection. Speaking of the cytoplasm of the egg he says, "This water soluble hyaline protoplasm coagulates with ease on mechanical injury. Mere compression will often cause an egg to coagulate in a solid mass." In this summary, he says, "A continuous but gradual application of mechanical injury can be sustained by a cell for some time without evidence of harm done. A short but rapid application produces instant local destruction, the spread of which may involve the entire cell. . . . Injury is accompanied by swelling and by an apparent increase in the acid reaction of the part involved." Continuous pressure that is very great must result at low temperatures; and it seems possible that coagulation like that described in the first quotation might result. According to Bancroft (938) one worker (Ehrenberg) thinks that the coagulation of colloidal solutions by freezing may be due, in part at least, to the pressure of expanding ice masses.

Keith (1043) obtained results which suggest that the disorganization of the protoplasm when frozen may be so brought about. He worked with *Bacterium coli* held at low temperature. At −20° C. in Boston tap water nearly all were dead in five days and all within a few weeks. Yet when the ice during freezing was worked into a spongy mass, like a sherbet, a large percentage of the bacteria remained alive for many months at −20° C. It is hard to see how anything but difference in the nature of the ice mass could explain the difference in the amount of injury to the bacteria held in the two kinds of ice. When the bacteria were held at −20° C. in water containing five to forty-five per cent glycerine, a large percentage remained alive for many months. Yet, according to Keith, glycerine at as high as twenty per cent concentrations is a mild antiseptic at temperatures above the freezing point of water. Like the work of Maximow these results indicate that toxic action is greatly reduced, if not eliminated, at temperatures much below the freezing point. They also indicate that, with these bacteria at least, encroachment of the ice mass rather than concentration of toxic substance, or loss of water, must have caused the injury. Keith suggests that in the glycerine solution the bacteria were extruded from the water cyrstals with the glycerine and lay in these glycerine masses without mechanical injury from the ice. (At −20° C. glycerine is a pasty mass but not rigid.) This seems the most plausible explanation of the results of Maximow. In the pure water the ice was solid and may have crushed the tissue; while in solutions the ice mass was not solid but contained masses of unfrozen water held by the material in solution; and the sections of tissue must have been nearly, or completely surrounded by such unfrozen solutions. In tissues at all succulent, when frozen in air the anastomosing of the ice masses into rigid networks enclosing masses of tissue, is delayed by materials in solution and by imbibition in the tissue. As the temperature falls the mass becomes more and more rigid, the increase in rigidity probably being rapid when the eutectic point is reached for some substance contained in a large amount in the cell sap.

We have seen that some tissues, such as the roots and buds of fruit trees, are more resistant to low temperature if they are wilted either slowly or rapidly before being frozen; and Molisch says that wilted tobacco leaves are more resistant than turgid ones. If freezing injury in the tissue were due to the pressure of the ice mass, then wilting should be expected to reduce the injury provided that, by the wilting the amount of water available to freeze should be so reduced that anastomosing of the ice particles into rigid masses surrounding tissue areas would require a lower temperature or would be prevented. With some very succulent leaves or flowers, wilting does not seem to increase resistance to freezing (967). It is probable that with such tissues the amount of water is so large that, even when a considerable amount is lost, there is still enough for the ice particles soon to become anastomosed into a continuous network perhaps as rigid as if no wilting had taken place. Wilting for only a few hours, however, increases the resistance of some tissues; and, if the killing of the tissue were due to loss of water or concentration of injurious substances, it is hard to see how such rapid wilting could increase the resistance. For the water is merely out of the tissue instead of being there to form ice; and after freezing the dryness of the protoplasm and the concentration of injurious substances should be the same whether, before freezing, the tissue were wilted or not.

We have seen also that dry seeds and pollen withstand very low temperature, while if permitted to imbibe water they quickly become much more tender. The seeds, on being dried again, acquire their former resistance. With seeds, merely getting the water out of the tissue seems to enable that tissue to withstand a temperature as low as it has been possible to attain. Of course, when the seeds withstood such extremely low temperatures there was no water in them for ice formation. If the killing should be caused mechanically by the ice mass, not only wilting but any other influence that might cause the ice mass to be smaller or less rigid should reduce the amount of injury. Sap solute materials having a low eutectic point by holding water unfrozen should have that effect. So, also should large amounts of stable water-holding colloids, such as pentosans in the cell walls. Such colloids in the protoplasm should have the same effect and might also cause the protoplasm to be more stable and therefore less easily disorganized by the encroachment of the ice mass.

Harvey (1022) found with cabbage that at the points on a leaf where crystallization begins first the injury is greatest. As Müller-Thurgau (1088) has shown, the water rushes to such points from neighboring tissue and the ice mass becomes much larger there. Since the water moves there from more distant as well as from adjacent tissue, it does not seem that the loss of water from, or the concentration of injurious substances in, adjacent cells would be greater than from those more distant. The most plausible explanation seems to be that, since the ice masses are larger at such inoculation points, some mechanical injury such as pressure or puncturing by these ice masses may cause the greater local injury.

In those mentioned here and in a number of other ways the behavior of frozen tissue seems to be most readily explained by a theory that killing results from mechanical injury to the protoplasm by the ice mass. It should be emphasized, however, that we have no conclusive proof that the protoplasm can be disorganized by any purely mechanical condition known to develop in frozen tissue; and it seems probable that we cannot learn, with certainty, just how freezing kills until we know more about the nature of the protoplasm. We know that when tissue is killed by freezing the protoplasm is disorganized so that semipermeability is lost; but we have no conclusive reason to think that this disorganization is always brought about in the same way. It seems possible that it might with some tissues be brought about, let us say, by loss of water, in some by concentration of injurious substances, and in some perhaps by pressure of the ice mass. However, it may in all cases be brought about in the same way, and that way may or may not be dessication; concentration of substances that, at such concentrations, are injurious; or mechanical injury from the ice mass.

Some Applications and Misapplications of Knowledge concerning Changes in Tissues During Freezing

Loss of water from tissue while thawing. Writers sometimes say that the water is withdrawn from the cell to form ice, and that if the thawing is slow enough for the water to be taken back into the cell before it is lost from the tissue death does not result, but that if thawing is rapid a fatal amount of water may be lost from the tissue before it can be taken into the cells. While the statement sounds plausible, it is evident to any one who has studied frozen plants that death is apparent before the water could be lost from the surface in injurious quantities after thawing. Observations suggest that when death first becomes apparent there is practically always more water in the tissue than would be necessary to keep it alive. Knowledge that all tissue shows as much injury when thawed in water as when thawed in air, and that some show more; that small groups of cells may be killed when surrounded by uninjured tissue; that seeds of young fruits may be killed when surrounded by uninjured pericarp; or that inner layers of sapwood may be killed when surrounded by uninjured bark and other tissue; should convince any one that water loss from the surface during thawing does not generally influence the amount of injury to frozen tissue. In so far as I know, no careful student of the subject of winter injury has explained death on such grounds. Sachs, the strongest exponent of the view that killing results from rapid thawing, suggests that with slow thawing the protoplasmic particles may have time to rearrange themselves before temperatures are reached at which injurious chemical changes may proceed rather rapidly.

Protective effect of materials in solution. We have seen that materials in solution in the sap of the plant may have some influence on the resistance of the tissue to low temperature. Thus, Lidforss (1052) and Schaffnit (1135) seemed to find sugar in the sap to lower the killing temperature; and Maximow found concentration of materials in solutions in which tissues were frozen very strikingly to lower the killing temperature. Water is held unfrozen in the tissue both by material in solution and by imbibition or colloidal absorption. Thus, the freezing point of tissue (the temperature at which ice formation will begin when supercooling is prevented) is always lower than that of the expressed sap. Carrick (963a) found the average freezing point of sap expressed from McIntosh apples killed in a firm ripe condition to be −1.621° C., while the average freezing point of the living fruit was −1.945° C. The larger part of the lowering of the freezing point in the tissue was due to the materials in solution; the smaller part to imbibition in the tissue.

Of course, since we do not know how freezing kills, we cannot know how materials in solution protect. According to the theory of Gorke (1011) and that of Harvey, only those substances in solution should protect that inhibit the precipitation of proteins. We have seen, however, that substances not thought to have this last effect, when in solution surrounding tissue or in it, do lower the killing temperature. If the killing was due to water loss, then materials in solution might protect by holding water unfrozen. If the killing should be due to pressures of the ice mass, or mechanical injury caused in some other way by the growth and increased rigidity of the ice mass, then the materials in solution would protect in the same way; for by holding water unfrozen the ice mass is kept slightly smaller.

The mistake is often made of assuming that the amount of protection furnished by the material in solution is equal only to the number of degrees that it lowers the point at which ice formation begins. The measure of the protection is the amount of water held unfrozen after enough water has been frozen out to leave a saturated solution. For example, let us say the freezing point of the expressed sap of one plant is 0.93° C. and of another 1.86° C. Then, assuming that the influence of the colloidal material in each plant is the same and that none of the materials in solution have eutectic points above the temperatures involved, there would be approximately as much water held unfrozen in the more concentrated sap at −14.88° C. as in the less concentrated sap at −7.44° C., or at −29.76° C. in the more concentrated as at −14.88° C. in the less concentrated sap. The solutions used by Maximow (page 555) would begin to freeze at −1.86° to −3.72° C.; but enough water was held unfrozen to furnish protection to the tissue at temperatures as low as −32° C.

No one has been able to get into the tissue of plants enough material to afford a protection remotely approaching the number of degrees found by Maximow when he froze thin sections in solutions. It is not easy to study the effects of materials in solution on the resistance. For cultural differences that cause differences in sap concentration cause other differences in the nature of the tissue, such as differences in the amount of colloidal material; and plants generally take up material from solution slowly and only in rather small quantities. Even this might change the tissue in other ways than merely to change its sap concentration. At the University of Missouri (967) the resistance of succulent summer tissue of plants could always be increased by causing cane sugar or glycerine to be taken in through cut stems. Potassium chloride solution had the same effect when it was taken up readily enough for the sap concentration to be appreciably increased. It was found also with the leaves of 36 species of plants, that those plants whose leaves were most resistant to low temperature tended to have leaves with the higher sap concentration, though there were many exceptions. Ohlweiler (1100) found similar results, and Harris and Popenoe (1021) seemed to find a slightly greater sap concentration in the leaves of the more resistant varieties of avocados. Probably sap concentration influences the amount of killing of fruit-tree blossoms. If the opening of blossoms is so slow that there will be time for more materials to diffuse into them from adjacent tissue, the resistance may be increased. It is probable, however, that with slow opening during cool weather the resistance of blossoms is increased more largely by other means than by increased sap concentration. It seems probable that with succulent tissues that are killed at rather high temperatures sap concentration is of some importance in determining resistance but is probably not the most important feature.

No experiments, in so far as I am aware, have shown an increase in resistance resulting from an increase in sap concentration of dormant tissue such as winter twigs and buds. Newton (1092) could find no relation between sap concentration and resistance to low temperature among varieties of winter wheat. Probably much of the sap solute has its eutectic point above the killing temperature of such tissue.

If material in solution should be important in determining resistance to cold, and killing at any given temperature should depend upon the going out of solution (crystallization) of some material thus permitting more water to freeze, it would seem that the time of exposure might be an important feature in determining the amount of injury. For with some substances crystallizing out is not as rapid a process as ice formation; and it might require a considerable time for the material to crystallize and thus release the water for ice formation. We have seen, however, that length of exposure greater than about thirty minutes does not seem to be very important in determining the amount of injury to fruit trees, either to winter dormant tissue or to blossoms. At Ithaca, New York, in the spring of 1921 peach blossoms almost completely open withstood a temperature of 22° F. for five hours, yet generally but a slightly lower temperature endured only twenty to thirty minutes would have killed them. The duration of the minimum temperature, then, influenced the killing temperature only slightly if at all. The same is probably true of dormant tissue. Certainly a temperature of −7° F. would not kill the buds or wood of fruit trees even though it continued for weeks; yet if the temperature fall is as rapid as it is possible to have it, that temperature endured for twenty to thirty minutes would generally kill the tissue. If at the eutectic point materials go out of solution (and permit ice formation) rather slowly and yet the length of time at which the plant is exposed to a given temperature does not strikingly influence the amount of injury at that temperature, then we have a further suggestion that the amount of materials in solution is not a major influence in determining resistance of tissue to freezing.

Relation of the nature of the protoplasm to hardiness. We have seen that, with some kinds of fruit plants, winter dormant tissue may withstand a temperature as low as −40° to −50° F., or lower; and that, during the period of most rapid growth, the tissue of the same trees might be killed by a temperature as high as 26° to 27° F., or higher. We do not know what changes may take place that render the tissue so much more resistant. With seeds, spores, and pollen, loss of water seems to be all that is necessary to bring about a condition of great resistance to freezing. However, we do not know that these have great endurance against large ice masses in the tissue; for when they are so dry as to withstand very low temperatures, it is probable that no ice formation occurs. With fruit-tree tissues there is generally no great difference between the moisture content in August and that in January. Yet, in the Northern Hemisphere, with apple trees in January the same tissue would probably withstand as much as 40° F. lower temperature than it would in August. And most of the tissues have in them large quantities of ice at temperatures considerably above that at which they may be killed. The change is, therefore, one that increases the ability of the protoplasm to withstand ice formation; though there may be also a reduction in the amount of ice that would be formed in the tissue at a given temperature. The sap concentration is but little greater in January than in August. Yet, we have seen that there seems to be something that moves back from the leaves that brings about a condition of hardiness in the wood. It may be that more of the sap solute of winter than of summer wood stays in solution at low temperature.

However, it is probable that of the material passing downward from the leaves during the hardening process that which is stored as stable water-holding colloids, such as pentosans, may be most influential in determining hardiness. Pentosans and other stable colloidal substances in the cell wall and in the protoplasm might reduce the size and rigidity of the ice mass by holding water unfrozen. However (Hooker, 1033), the pentosan content of tree tissues does not seem ever to be large; and in the results of Rosa (1127) as large a percentage of the water was frozen at −4° C. with hardened cabbage plants as at −3° C. with tender plants. The difference in hardiness was greater than this might indicate. In some of Rosa's studies he extracted pentosans by boiling the tissue in a weak solution of hydrochloric acid; while in others he extracted with hot water only, as pectin, a related substance, is extracted in jelly making. He found that with cabbage plants, which can be hardened, this part of the pentosan content which can be extracted with hot water increased considerably during hardening. He thinks that pentosans released by merely killing the tissue with hot water may be in the protoplasm. In other words, increasing the pentosan content of the protoplasm seems to increase its resistance to freezing. In tissue of the tomato plant only a very small amount of pentosans can be extracted with hot water; and this plant cannot be caused to acquire appreciable resistance to ice formation.

Since it seems to be the pentosans in the protoplasm that cause increased resistance, and since the amount of reduction in ice formation that could be caused by the rather small amount of pentosans in the protoplasm of the most resistant plants is rather small, it seems probable that pentosans and other colloidal substances may increase the hardiness of the tissue by increasing the colloidal stability of the protoplasm. It would seem that fats, in combination with other substances, might have the same effect. Fischer (992) and others have found that there are great differences in the resistance of different colloids to low temperatures. Some are irreversibly changed by freezing, while others are not. The same colloid seemed more resistant when newly formed than when older. Quoting the experience of Rein, who was unable to induce any of a large number of tropical plants to acquire appreciably increased resistance, Fischer suggests that a condition of the protoplasm most favorable for growth seems to be one that is not resistant to freezing. He thinks it probable that, since in tropical countries the temperature would always be favorable for growth, those plants most able to develop rapidly would have the advantage as to light, food supply, or water supply, and would therefore be most likely to survive. If a protoplasmic condition most resistant to freezing was not one favorable for such rapid development, then in the tropics no plants would tend to have such a resistant protoplasm. On the other hand, in colder climates the development of such a resistant protoplasmic condition, even though it was not one suitable for the most rapid growth, would be necessary for survival. While we cannot be certain, it seems very probable that, for the most important feature explaining the differences in resistance of tissues to low temperature, (at least when there are excepted seeds, spores, pollen, and other tissues that can withstand drying so complete that no ice formation occurs) we must look not for minor influences such as sap concentration or moisture percentage, but for differences in the nature or composition of the protoplasm.

Supercooling and injury from low temperature. We have seen that the tissue is not injured unless ice formation occurs; and also that if kept very still the tissue may remain for a number of hours supercooled to several degrees below its freezing point or even its killing temperature. This suggests that supercooling may be an important means by which the tissue may escape injury. However, in the open, where there is always some jarring of the tissue, supercooling is so slight as to be of very little, if any, practical importance. This seems to be true also of fruit being hauled in refrigerator cars. Some workers have been inclined to ascribe a good deal of importance to the protective action of supercooling in storage rooms. Thus, if in a series of freezing experiments, let us say with apples, in which the fruit is not jarred and in which there is a gradual fall of the temperature, ice formation does not begin at a temperature above 25° F. though the actual freezing point is about 28° F., it has sometimes been assumed that the tissue is safe if the temperature does not go as low as 25° F. As a matter of fact, such a conclusion would not be justified even for storage conditions; for supercooling is not a dependable phenomenon. While the tissue might remain supercooled for several hours, if held at its actual freezing temperature for a considerable period (say several days), ice formation would always occur. Thus, Carrick (1216) found that apples held at 0.68° C. below the average freezing point remained supercooled only one to three days, after which ice formed in the tissue. Even if the fruit were to be held in storage for but a few hours at a temperature below its freezing point, the jarring attendant upon moving it out of storage would generally cause ice formation. It seems, therefore, that little use can be made of the phenomenon of supercooling in handling fruit or vegetables. It is not improbable that in greenhouses, where there has been no jarring and where the freezing temperature has continued but a short time, plants have remained supercooled through the period of low temperature and thus escaped injury.

With tissues that show greater injury when the temperature fall is rapid, it is probable that supercooling to several degrees below the temperature at which ice formation should begin might cause increased injury. For with such supercooled tissue ice formation, once it had begun, might proceed more rapidly than it would with a rather rapid temperature fall when there was no supercooling. However, resistant dormant tissues, whose killing temperatures are most largely influenced by the rate of temperature fall, are generally frozen under conditions such that there is very little supercooling.

Summary. In this chapter we are concerned only with direct freezing to death; when so killed, the tissue has, after thawing, a brown water-soaked appearance. The protoplasm is disorganized and has lost its semipermeability. Injury of this specific kind does not seem to occur unless ice forms in the tissue; though long exposure to temperatures above the freezing point may cause a slow dying of the tissue.

We have no satisfactory explanation of how ice formation in the tissue causes such disorganization of the protoplasm. The theory that it is caused by the withdrawal of water from the protoplasm in ice formation does not seem to enable us to explain all experimental results. Neither does the theory that it is a precipitation or an irreversible change in the colloidal nature of the protoplasm caused by concentration of the sap or changes in its composition, as water is frozen out and substances reach their eutectic points. The theory that the disorganization of the protoplasm is a mechanical injury caused by the ice mass seems to explain more of the experimental results with the freezing of plants than does either of the others; but we have no conclusive proof that such a change in the protoplasm can be brought about by such mechanical injury.

Materials in solution influence at least slightly the killing temperature of succulent plant tissues; but we have no proof that they are of any importance in determining the hardiness of winter dormant tissues or that they are of major importance even with succulent tissues. The presence in the protoplasm of colloidal substances, such as pentosans, seems to be of more importance; probably because such substances increase the colloidal stability of the protoplasm and thus increase its ability to withstand ice formation in the tissue.

CHAPTER 23

CONDITIONS THAT AFFECT THE MINIMUM TEMPERATURES IN ORCHARDS AND MEANS OF AVOIDING INJURY

This chapter concerns means of avoiding extremely low temperature. Since it has to do more with the physics of the air than with responses of fruit trees, only reasonably well established principles will be discussed, less attention being given to evidence. For more critical discussions, the student should seek publications in meteorology.

A brief discussion of air temperatures seems necessary to a clear presentation of the practical considerations of this chapter. The average temperature of the air, up to something over six miles, generally becomes lower with increasing distance from the surface of the earth, the average being about 1° F. for each 300 feet. This rate is modified by a number of conditions for any particular time and place, among which are atmospheric pressure, cloudiness and the degree of saturation of the air; and applies only to the free air. Along the sides of elevations on the earth the rate varies. For example, the decrease in temperature for altitude was found by one worker (quoted by Humphreys 1037) to be 1° C. for each 180 metres on mountain-sides, 200 metres on hills, and 250 metres on plateaus.

Heat is constantly radiated from the earth and bodies on it. During the day the amount of heat received is generally as great as that lost by radiation, or greater. During a still clear night, heat may be lost from the surface of the earth, or from exposed objects much more rapidly than it is received, the loss being more rapid from a body exposed directly to the sky. Thus, cooling by radiation is more rapid on top of a hill than on the side, or from a body lying horizontally, than from one standing perpendicularly. Dark-colored objects, in direct sunlight, absorb the sun's rays and sometimes reach a temperature well above that of the air. Such dark-colored bodies, exposed to the clear sky at night, radiate heat more rapidly than do lighter-colored ones, and may be cooled to a temperature considerably below that of the air. However, even light-colored objects exposed to a clear night sky, particularly during periods of high barometric pressure, and when there is little or no wind, are cooled by radiation to temperatures below that of the air. The air is then cooled by contact with the earth or objects covering it.

This radiation from the earth and other bodies and cooling of the air gives rise to what is known as temperature inversion. That is, on such still clear nights the air temperature near the earth may come to be lower than that at somewhat higher elevations. Young (1179), by using thermometers on a tower, found in Southern California as an average during forty clear nights the following temperatures. At an elevation of five feet, 32.5° F., ten feet, 33.7° F., fifteen feet, 35.1° F., twenty feet, 35.9° F., twenty-five feet, 37.2° F., thirty feet, 38.4° F., thirty-five feet, 39.0° F., and at forty feet, 40.5° F. Except in valleys between rather high hills this layer of cold air is generally a shallow one; but it varies, being influenced by the condition of the atmosphere and the nature of the previous day. Large temperature inversions occur more often in winter than in summer; and the inversion is steeper when the humidity is low than when it is high.

These temperature inversions, due to radiation, are probably the cause of much killing of wood or buds in winter, and of blossoms, fruit, or other tissue in spring. It should not be assumed, however, that, in all sections, killing temperatures can be brought about only by such local radiational cooling; or that the extent of inversion measures the degree of danger. The degree of inversion (the rate at which the temperature increases upward from the surface of the soil, and the depth of the cold layer) is greatest following still clear days with rather high maximum temperature. On the other hand, according to Young (1181), the most severe frosts in some sections usually follow cold, windy and even cloudy days. During nights following such cloudy days the temperature inversion is below the average. Even then radiation could still be of importance in cooling the air the last few degrees necessary for a killing freeze or frost. In some of the fruit districts of California, it seems that local radiational cooling is usually, though not always, responsible for killing temperature; with a wind of more than very slight velocity the temperature rises, or at least does not fall appreciably, during such nights.

Sometimes, however, the air is cooled much more rapidly than would be possible by radiation alone. A rather simple example of temperature fall, that is not caused by radiation, in the section involved, is cited by Hollenbeck (1019) for the fruit district of Roswell, New Mexico. Often, between midnight and sunrise, the wind at the surface shifts to the northeast and there is a sudden drop in temperature. This seems to be a draining in of colder air from a higher section where conditions for cooling by radiation are more favorable. In level countries, where this draining in would not be possible, serious spring freezes may occur when there is a strong wind with cloudiness or snow, conditions unfavorable for cooling by radiation. Sometimes cooling is more rapid than could be brought about by local radiation or by a cold wind along the surface of the earth. Brooks (957) explains this as follows:

> After the temperature at one kilometre above the surface has fallen to 10° C. colder than that at the surface, any further fall will be accompanied by a convectional interchange and an equal fall in temperature at the surface, the upper wind descending in a sudden gust and routing upward the masses of warmer air near the surface. The temperature of the wind when it reaches the surface will be about 10° C. higher than when it started down from one kilometre. Nevertheless, its temperature will be lower than that which prevailed immediately before the gust arrived from aloft; otherwise it would not have come down. If the surface wind is fifteen miles an hour, that at one kilometre is likely to be thirty miles an hour; although its component from the direction of the surface wind may not be more than twenty-five miles an hour. This being the case, if the surface wind would in the course of the night lower the temperature at a place 5° C. merely by transportation along the surface, the fall to be expected would be nearly 5° more because of the wind aloft. Stronger winds and radiation from a snow surface into a clear sky at night would make extreme falls in temperature. Therefore, in forecasting the temperature change in a cold wave, the probable transportation of cold air at a moderate height is of more importance than that along the surface.

The temperature of tissue during rapid radiation at night. It is well known that during a night favorable for loss of heat by radiation an object may reach a temperature several degrees below that of the air at the same level. Thus, the temperature of an exposed thermometer may be several degrees below one in a shelter near it. This suggests that tree tissues during such nights in winter and spring may also reach temperatures below that of the air. With succulent tissue, such as fruit blossoms, cooling may be further hastened by evaporation. On this account the air temperature as indicated by sheltered thermometers may give little indication as to the temperature endured by tissues exposed to a clear sky. As to how common it is for such tissues to be at freezing temperatures appreciably below that of the air we do not know, and with blossoms and very young fruit it would be very difficult to learn. The temperature could be measured by means of thermocouples; but to be dependable, such measurements would have to be made on a considerable number of cold nights favorable for radiation.

Blossoms and some young fruits will withstand a temperature several degrees, and winter tissues many degrees, below that at which ice formation begins. Cooling by evaporation must be very slight from frozen tissue; and cooling by radiation must be slower during freezing because of the heat liberated by ice formation. It seems that at temperatures above the freezing point, during a night favorable for radiation and evaporation, the difference between the air temperature and the tissue temperature should be greater than the difference between the temperature shown by a sheltered thermometer, and that shown by an exposed one; but it seems that at temperatures low enough for ice formation, the difference between the tissue temperature and the air temperature should be less than the difference in temperature between exposed and sheltered thermometers. In rather humid sections I have examined orchards after a number of spring freezes during clear nights and have never found differences in killing between fruits or blossoms exposed directly to the sky and those among the foliage. In sections where the humidity is low and the sky very clear, it is probable that blossoms or young fruits may be killed sometimes by reaching temperatures below that of the air, but it seems probable that except with very tender parts such as strawberry pistils this rather seldom happens in reasonably humid climates.

With winter hardy tissues it seems probable that this is still less common. Thus, Mix (1085) found that at Ithaca, New York, the temperature fall just beneath the bark on the trunk of large apple trees generally lags behind that of the air surrounding it, the temperature at the time of the minimum being generally several degrees above that of the air. Small tree-trunks, with a diameter of but three or four inches, followed more closely the air temperature, but did not fall below it. These trees were headed high and radiation from the trunk was probably more rapid than from the trunk of low headed trees. However, it is not impossible that much more extensive study would disclose some nights when the trunk temperature would be lower than the air temperature, and smaller tissue masses might often be so; but it should be remembered that, on these cold winter nights as the temperature falls, more ice is formed and heat is thus liberated.

Air drainage. One of the most important means of avoiding loss by low temperature is in the choosing of the location for the orchard. In making such a choice air drainage is of great importance. In some situations, particularly in mountain regions, the different features that determine the temperature at a given position are very complicated and many peculiar local conditions must be considered. The general principles involved are reasonably simple. Air drainage is of importance during still clear nights when there is large temperature inversion. We have seen that during such nights, except in deep valleys, the temperature of the free air rises rather rapidly from near the surface. In the case of a hill sloping downward into a valley, air in the valley will be cooled by contact with the valley floor, which is cooled by radiation; and unless the valley floor is one with a slope that permits a rapid flowing out, this cold air may remain in its position. The air in contact with the hillside and on top of the hill will be cooled in a similar manner. If the slope is gentle, the cold air may flow slowly down the side of the hill; and except very close to the top and to the bottom of the hill the temperature about five feet from the ground may be nearly uniform. In Figure 54 from Young (1178) are shown the minimum temperatures at different points on a hillside near Pomona, California. The temperature indicated at each point is the average minimum for twenty-nine clear nights. It will be seen that along the gentle slope from an elevation of more than 1200 feet down to 1000 feet, there is little difference in minimum temperature five feet above the surface of the soil. The temperature becomes very much higher toward the top of the steep slope at the left and of that at the right. It seems probable that on the gentle slope the air cooled by contact with the soil and vegetation moves slowly down close to the hillside mixing little with the warmer free air. This is because the slope is so gentle that the cold air is nearly directly under the free air. At the steepest slopes the tendency of the cooled heavier air would be to move out over the cool air at the surface below and to be replaced by the warmer adjacent free air. It is probable that there might have been more tendency for the higher positions on the gentle slope to show a higher minimum temperature if it had not been for the large area of the hill at the left. That is, around the top even of a gently sloping hill there should be some mixing with the warmer free air. Another point of interest is the depression below the hill toward the right, where the temperature is very

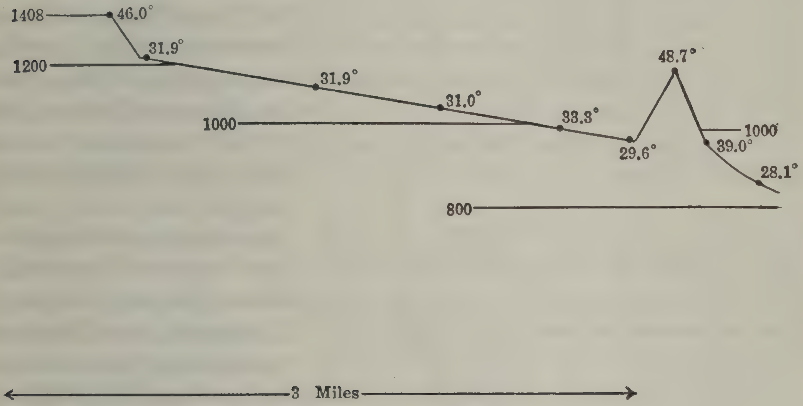

FIGURE 54. (After Young.)

low. In such depressions, on a gentle slope, the air may be nearly as cold as that on the valley floor.

On a steep slope the replacing of the cooled surface air by the warmer adjacent free air is more rapid. What might be expected on a steep slope during a still clear night may be made clear by the accompanying figure used by Humphreys (1037) to illustrate a typical morning temperature inversion such as follows a still clear night.

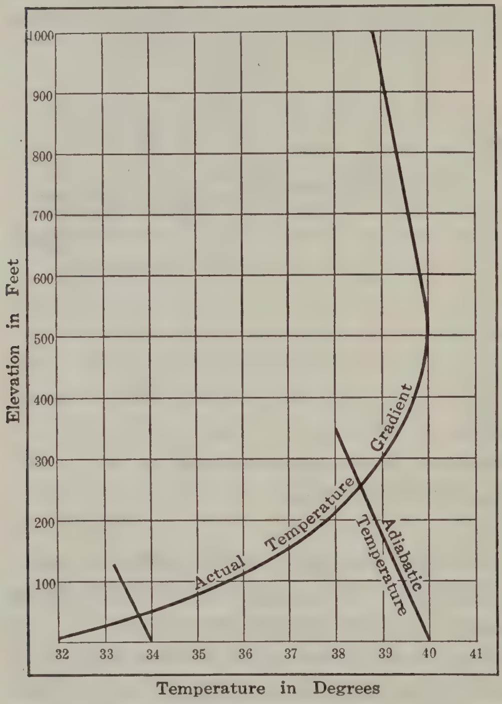

FIGURE 55. (After Humphreys.)

With increasing elevations up to 500 feet the temperature rises; above that elevation the temperature becomes increasingly lower. On such a morning, considering the temperatures along the surface of a rather steep hill, 1000 feet high, the warmest part of the hillside, the thermal belt, would be at the elevation of 500 to 600 feet. In a system of hills or mountains the thermal belt might be considerably higher. We do not have to assume continuous steep slopes in order to have protection. A bench on the hillside with a steep slope below might be nearly as warm. Thus, on a mountain-side, benches at certain elevations above the base might be very safe positions for fruit growing. The height of the warmest position on the hillside would, of course, not be the same on each clear morning.

The temperature inversions vary in depth. With low, gently sloping hills the top is the warmest on such mornings, even though that position is most favorable for radiation. With higher, steeper hills, however, the top may extend above the inversion layer into air which, at night as well as during the day, is cooler the higher the elevation. If the hill sloped down to a valley with a hill on the other side, the air at the bottom would be colder than if the hill were on a broad plain. The layer of cold air in the valley between two opposing hills would be deeper than the normal inversion layer on a plane. Thus, Cox (976), who studied temperature inversions in the mountains of North Carolina, found that the thermal belt is lowest on a mountain with no opposing slope near and with a large mass at the summit. On one such mountain the center of the thermal belt was generally about 400 to 500 feet above the valley floor. While on a mountain 1760 feet high with an opposing slope the center of the thermal belt was 1200 to 1300 feet above the valley floor. In other words the layer of cold air (inversion layer) was more than 1100 feet deep. In fact, with mountains having such opposing slopes, and leading up to small knobs, the warmest air on such still, clear nights was at the knobs unless the mountains were more than 1100 feet high. The thermal belts were lower, and the tops colder, on mountains with massive tops to radiate heat.

While the upper part of these mountains was found free from frosts that were due to inversions on still clear nights, winter and spring freezes not due to inversions sometimes occurred late enough to injure fruit crops. It should be kept in mind that in some sections freezes come when there is a strong wind and little or no inversion. Such freezes are as severe, or nearly as severe, on the hill as in the valleys. In fact, according to Young (1181), during the coldest winter nights at Pomona, California, and the coldest spring nights at Medford, Oregon, the temperature inversion gradient is not very steep; and when there is much injury in the valleys there is generally some injury on the hillsides. In fact, in some sections such freezes often result in greater injury on the hills than in the valleys. The colder air in the valleys, due to inversion during previous nights, will have delayed the opening of the buds, and thus have caused them to be more resistant than those of trees on the hills.

Another limitation of air drainage is near bodies of water. There the lowest land nearest the water tends to have the highest minimum temperature. In hilly areas, far enough back from the body of water for its influence to be rather small, the effects of the body of water and of air drainage may sometimes be conflicting. Thus, the lowest ground might tend to be warmed the most by being closest to the body of water, but this warming effect might be partially or largely balanced by the cold air coming in from the hills. During clear nights, when only a gentle wind blows from over the water, the warming effect of the body of water will be distributed over much of the slope on the side of the water body toward which the wind blows. This nearly equal temperature along a rather steep slope facing a body of water, across which the wind is blowing, is probably a result of the complicated influences of air drainage and of the warm wind. On the other hand, when the wind is from over the land and therefore tends to be colder than the air around the body of water, the air over the lowest land next to the lake may be the warmest because the cold wind is lifted by the hill. If the hill were less steep, so that the cold wind would move along its surface, the temperature near the body of water would be that of the wind. These are only a few of the complications that may be found near bodies of water where, during the night, air drainage is to varying extents offset by the warming effect of the water.

Another complication in air drainage may be found in intricate mountain systems, where a bench, which from its elevation might be expected to be in a thermal belt, receives streams of cold air from neighboring, or even rather distant areas, of higher elevation.

Height of trees. Closely related to air drainage is the influence of the height of trees. During nocturnal temperature inversions, unless the layer of cold air is very deep, as in valleys between opposing slopes, the top of a tree thirty or forty feet high will be in a warmer atmosphere than that of one not so high. Thus, Young (1179) found as an average minimum temperature of forty clear nights, 35.1° F. at an elevation of fifteen feet, 37.2° F. at an elevation of twenty-five feet, 39.0° F. at an elevation of thirty-five feet and 40.5° F. at an elevation of forty feet. During a still clear spring night the top of a tree fifteen to twenty-five feet high might be in air enough warmer for the fruit in the top to escape injury. Even if the cooling of the fruit or flower is by its own radiation, there will be warming by contact with the warmer air. In the northeastern part of the United States many apple trees are more than thirty feet high. It should be remembered, however, that except in regions very favorable for radiation, more often than otherwise, the weather conditions during these spring freezes are such that the temperature inversions are rather slight; and it is doubtful if in good fruit-growing sections enough fruit would be saved by having the trees so tall to repay the extra cost and inconvenience. Marked temperature inversions generally accompany the coldest nights in winter; and so the tops of tall trees will generally be in the warmer air. However, except with the peach, with which tall trees are not practicable, and with citrus fruits, with which orchard heating must generally be practiced, wood killing is the most common type of winter injury; and wood of the trunk and at the base of the branches is generally the most tender. Nothing is gained by having the top of the tree alive if the trunk is killed.

Windbreaks. The question of windbreaks is closely related to that of air drainage. We have seen that except on very gradual slopes from broad hilltops, air drainage is not so much a flowing of the cold air down the slopes as a replacement of the cold air on the hillside by the warmer free air approximately on the same level. The greater the amount of wind striking the slope the more rapid will be the mixing and, generally, the warmer the air near the soil. During very windy nights there is little difference in temperature between hills and valleys. The wind thus plays an important part in reducing the injury from cold airpockets. Experience indicates that a valley crossed by the prevailing wind during a cold, still night may be colder than one parallel with the wind. With the latter kind there may be some mixing of the warmer free air with the colder air near the soil, even though the wind is very gentle. Unless the location is one where it is warmed by some peculiar local influence, such as a body of water, generally during a night favorable for radiation the air above the soil will be warmest in the windiest location.

It is clear, therefore, that during a night favorable for temperature inversion, a windbreak above the orchard, or even below it, might tend to cause a frost pocket; and certainly a windbreak on the side from which comes what slight wind there is, may reduce the amount of mixing of the cold surface air with the warmer free air. In a level area, or one nearly level, a windbreak, by lifting what little wind there is, may cause a frost pocket behind it. It is not uncommon to see fruit blossoms, particularly strawberry blossoms, killed in the still air behind a windbreak when in the remainder of the field they are uninjured.

While a windbreak may cause injury, it may also be beneficial. The soil is cooled faster in a wind. Masses of cold air are being brought constantly into contact with it. Therefore, in sections where the soil freezes so deeply that the roots are sometimes killed, a windbreak may be beneficial; and it may be desirable in such sections either to choose a site that is protected from the prevailing winds during cold waves or to plant a windbreak.

In some sections the soil may become so dry by winter that it freezes much deeper and the roots become colder. A windbreak, by keeping the drying winds out of contact with the soil, may prevent root killing, both by reducing the drying and by reducing loss of heat from the soil to the cold winds.

Where the orchard is warmed during cold nights by an adjacent body of water, a windbreak on the landward side might, by lifting occasional cold winds that blow from over the land, prevent the warmed air from being moved out of the orchard. In some coastal sections where in summer cold winds from the ocean during the day tend to keep the temperature too low for satisfactory development of the fruit, a windbreak may deflect the cold wind over the orchard and cause it to be warmer while the sun is shining. Probably when the sun is not shining to heat the cold air settling into the orchard from the upward deflected wind, there will be little difference in temperature caused by the windbreak except that in the soil protected from the wind some heat will accumulate and for a time after sunset this may influence appreciably the temperature of plants such as strawberries growing close to the soil. It is doubtful if the amount of heat radiated would appreciably influence the temperature of trees; and so with them under such coastal conditions, the windbreak would probably influence the temperature appreciably only during sunshine.

Of course, a windbreak might prevent the blowing off of fruit and the breaking of trees in summer or autumn, but after the trees have become large enough to occupy all of the land they may serve that purpose nearly as well as the windbreak. And the outer rows, those taking the place of the windbreak, will bear fruit much of which will not be blown off.

It seems probable that in so far as protection from freezing is concerned in sections where root killing is not common and where killing of buds or blossoms is rather common, a windbreak may be harmful more often than beneficial. In sections where neither root freezing nor bud or blossom killing is common, the windbreak will not generally be worth the cost. These two groups probably include much the larger part of the fruit industry of the United States.

Choice of slope. The direction of slope influences, to some extent, the safety of an orchard from frosts. During a still, clear night when there is temperature inversion, unless the hill is very steep, the slope in the direction from which comes what slight wind there is will be the warmest, other conditions being equal. For the cooled air coming down from the top of the hill will be more quickly replaced by the warmer adjacent free air. In sections where the wind during cold nights tends to be from the north, peach buds are sometimes injured worse on a south slope than on a north one, even when the freeze comes so early in winter that there can be little or no difference in the condition of the buds. During such nights, the temperature must be a little higher on the north slope than at the same elevation on the south slope.

On a north slope in the northern hemisphere, growth may be delayed in spring, and danger of loss from late freezes may thus be reduced. The amount of retardation, however, depends upon the nature of the crop as well as the nature of the slope. The soil on the south slope will be warmer during the day because it receives the rays from the sun more directly. In other words, a given soil area on a south slope receives more heat from the sun than a similar area on a north slope; and, during sunny days, air in immediate contact with the soil will on a south slope be warmer than on a north slope. Low growing crops, such as strawberries, will therefore develop more rapidly in spring on a south slope.

However, this is not always true of trees. The rate at which growth starts in spring is largely determined by the temperature of the buds and not by that of the roots. The day temperature of the air around the tree top is affected but slightly, if at all, by the soil temperature. Of course, with large mountains the temperature on the north slope might, in spring at least, be lower during most of the day, but this would not be true of smaller hills. The temperature of the twig in direct sunlight may be several degrees above that of the air. Since the tree stands erect, and not perpendicular with the slope, twigs of similar trees on the north and south side must receive the sunlight with equal directness. In actual experience, on low hills with gentle slopes, though strawberries bloom earlier on south than on north slopes, there will be little, if any, difference in the blooming time of tree fruits. On steeper slopes, however, particularly in sunny climates, blooming may be the earlier on the south slope, the difference being caused by the difference in the proportion of the day during which the twig is in the sunlight. On the south slope the tree toward the sun is always on lower ground than the one next north of it, and so the shadow of one tree seldom extends to the next. On a north slope the tree nearest the sun will always be higher than the one next north; and, during part of the day at least, may throw a shadow across it. In Figure 56 is represented what might be expected when rays from the sun at uniform angles with the horizon strike trees on the north and the south side of a hill with steep slopes and one with gentle slopes.

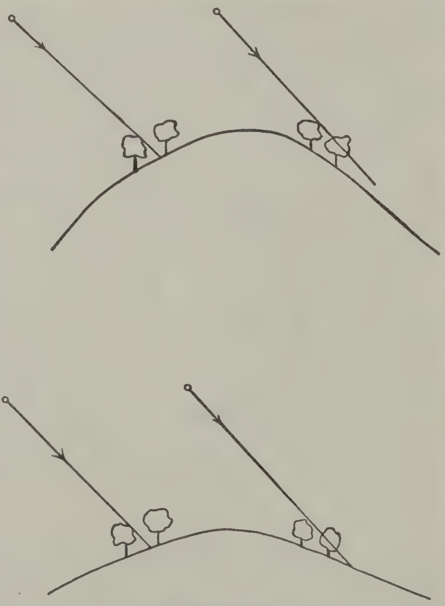

FIGURE 56.

Of course, the larger the trees and the closer they are planted the more of the time any twig will be in a shadow. On a rather steep north slope the hill itself will throw a shadow on some of the trees during a part of the day. The amount of heat absorbed by the twigs from the direct sunlight, then, is less on a rather steep north slope, not because of a difference in directness of the sunlight, but because they are in the direct sunlight during a smaller part of the day. This is true particularly in late autumn, in winter and in early spring. On such a north slope, steep enough for the tree to be in a shadow during part of the day, there will thus be less pushing of the buds during warm sunny days in winter and very early spring; and so in very sunny climates there may be less danger from late winter and spring freezes. On the other hand, if the slope were more gentle, or the trees farther apart or lower, or if no warm weather should prevail until the sun was more nearly directly over the trees, there would be very little difference, if any, in the time of starting or the rate of growth of the buds of trees growing on the north and on the south slope of a hill. At latitudes such that the rest period is very important in determining the time of starting of the buds, blooming of trees on the north and the south side of even a rather steep hill might be at about the same time.

What is said in this section applies to the northern hemisphere. In the southern hemisphere, of course, the north slope would be the sunny slope.

Bodies of water. Because of its great specific heat and the latent heat of fusion, a body of water fluctuates in temperature much less than does the soil or the soil covering. It, therefore, has a marked effect on the maximum and minimum temperature of air passing over it. If the body of water is large it may influence the air temperature over the land for a considerable distance. Wind passing over a body of water is cooled during warm days and warmed during cold nights. Such a wind causes blooming to be later and killing freezes to end earlier in spring. If the body of water freezes over during winter, it may have little influence on the winter temperature in bordering orchards; but after thawing it may have a marked influence in reducing the danger of late spring freezes. A deep broad lake may not freeze over during the coldest winter at latitudes as high as 45° or higher.

The commercial peach and grape industry in the northern and the northeastern part of the United States is possible, and the apple, pear, plum, and cherry industry is much safer, because of the presence of the Great Lakes. The prevailing wind during cold nights is generally from the north or northwest; and so the orchards bordering these lakes on the south side, and sometimes on the east side, are in much less danger from extremely cold nights; fruit, particularly of the grape, which ripens late, is in less danger of being killed by early autumn frosts and there is less danger of killing of wood, buds, or blossoms during winter and spring; often the wood is better hardened for winter because the leaves are not killed off so early in autumn. The trees of some species seem to be more vigorous because of the steadily cold winters and the cool summers. The distance from the lake to which the protection extends must vary with conditions during the cold night. Certainly the further back from the lake the orchard is located, the greater will be the danger that the wind will not be in the right direction for the greatest protection during some cold night.

There are many local complications that may enter into the influence of a body of water (especially a small one such as a large river or a narrow lake) on a particular area. If the district is not one with which the results of experience are available, a very minute study as to depth of water, direction of winds during periods of high barometric pressure, nature of slopes, bends in water body, and other features must be made before a decision as to the probable safety of the section can be made with any degree of certainty.

Methods of delaying spring starting of growth. Since, with most fruits, there is, generally, a decrease in resistance to freezing from the time buds begin to swell until the young fruit is of considerable size, it follows that the later in spring a fruit tree blooms the less the danger from spring freezes will be. For many sections, late blooming is one of the most important features which determine profits in fruit growing. The delay in blooming, and in the beginning of spring growth caused by bodies of water, such as the Great Lakes, may be nearly as important as the warming of the air during a cold night.

We have seen that, in the southern part of the temperate fruit-growing region of the United States, the trees are not yet so completely out of the rest period when spring temperatures favorable for growth begin but that growth is much slower than it would be at similar spring temperatures where the winters are longer. In the southern half of the United States there seems to be greater danger of freezing temperature after there has been a considerable period warm enough for growth than in the northern half. Therefore, this slower response to favorable temperature for growth is probably of great value in a number of important fruit-growing sections, such as the valleys of California and the peach belt of Georgia.

With strawberries, it is possible in cold sections, to delay blooming by covering the plants with straw, or other material, in winter; leaving it on rather late in spring. The strawberry blooms very early in spring, when the temperature of the covered plants is kept low by the cold soil. Grapes, raspberries, and dew-berries can also be covered and thus protected against winter freezes; but on account of their blooming late it is not generally possible by such a covering to influence the blooming time without danger of smothering the young shoots. Even with the strawberry, care must be taken to uncover the plants before they are injured by their starting growth without sufficient light.

Since it is possible by means of a thick mulch appreciably to delay the warming up of the soil in spring, that practice has been used as a means of delaying the blooming of fruit trees. However, the temperature of the tree is not kept perceptibly lower; and it is the temperature of the twigs that influences the rate of development; the temperature of the soil having little influence on the opening of the buds. Bailey (932) mulched some gooseberry plants so heavily that there were still snow and ice under the mulch on April 13th. Twigs covered by the mulch were fully dormant, but those projecting through it were as forward as adjacent plants not mulched. If buds on twigs just above the frozen soil were not delayed by the mulch, it seems improbable that buds well above the soil on fruit trees could be delayed.

We have seen that Müller-Thurgau (1088) emphasized the importance of the pigments in the leaves and twigs of trees in absorbing sun's rays and thus maintaining the tissue in direct sunlight at temperatures well above that of the air; and that Whitten (1165) showed that the development of peach buds in late winter and early spring can be very appreciably delayed by keeping the twigs covered with whitewash to prevent absorption of heat. Crops of fruit have been saved in this way. However, the practice seems to be of very limited value because of the expense and because of its limitations. With peaches the buds would often be killed regardless of the whitewashing; the temperature going low enough to kill the buds when fully dormant. Further, whitewashing would not always delay the blooming enough to prevent the flowers from being killed by a spring freeze. In a cloudy section, such as the eastern part of the United States, it would delay it very little. Even in sunny climates spring freezes would often kill the blossoms or young fruits in spite of delay in blooming caused by the whitewashing. The whitewashing would have to be done in the years when the crop was lost anyway, and in the years when no killing freezes occurred, as well as in the years when a crop would be saved. Ten dollars an acre seems a low estimate for the annual cost; and if but one crop in fifteen years were saved, the cost of that crop would be one hundred and fifty dollars an acre and interest on the annual cost. It would probably cost much more in fact. Obtaining late blooming varieties seems, therefore, to be the only effective means of causing blooming to be late enough to avoid spring freezes.

Orchard heating. Of considerable importance, under some conditions, is the warming of the air in the orchard. One method often mentioned is spraying with water. This might be expected to raise the minimum temperature of the fruit in two ways, by furnishing heat to the air, and by preventing the radiating of heat from fruit or blossoms. Thus, Nichols (1095, 1096) thinks that for this reason fruit or blossoms may withstand a lower air temperature when the night is cloudy, and even when the fruit is covered with ice or snow than during a clear night, the explanation being that the cloudiness or snow prevents the fruit from reaching, by radiation and evaporation, a temperature lower than that of the air. He describes an observation on April 23–24, 1913, when temperatures of 21° to 25° F. did a considerable amount of damage to apple blossoms not yet fully open, and another on April 19–20, 1916, when young fruits were frozen hard during the night when, at its beginning, the trees were so wet that the fruit froze with snow and ice on the surface, and enough fruit was left alive for a fair crop. He does not give the air temperature during this last period. Further, while the unopen blossoms are generally more resistant than the fruit, they may not always be so. We have seen in Chapter 21 that spraying trees with water during a cold night is a dangerous practice. West and Edlefsen (1163) sprayed water above each of a considerable block of apricot trees during a cold night and found that in the orchard only on the sprayed trees were the blossoms injured. In a greenhouse where all of the heat is retained and where cooling is less rapid this might be an effective practice.

Another practice that is often recommended is called "smudging." It is the burning, in or at the side of an orchard, of some material that gives a very dense smoke that will cover the orchard. It is assumed that this will maintain a higher temperature in the orchard by reducing radiation. Much experience and some experimental evidence (Kimball and Young, 1045) indicate that retardation of radiation by smoke clouds is of no importance in protection against frosts or freezes.

It has been found possible to protect deciduous fruits against spring freezes and subtropical fruits against winter freezes by actually heating the air in the orchard. It is, of course, not practicable to protect dormant deciduous fruit trees against winter freezes; for no one would work in an orchard at such low temperatures. It is not necessary to review here all of the evidence indicating that by the use of small fires (fifty to one hundred or more to the acre) it is possible to raise the air temperature several degrees and generally to prevent the killing of the blossoms or of the fruits by a spring freeze; or, in a subtropical region, to prevent the killing of blossoms, the fruit or the trees by exceptional winter freezes. When orchard heating other than smudging was first being considered, it was suggested by some that heating could not be effective because the warm air rises and is moved from over the orchard by winds, therefore it would require heating all out of doors. Experience, however, has shown that it is easier to heat a large area, but that even as small an area as one acre can be satisfactorily heated. Experience has indicated, also, that heating is more effective when many small fires rather than when a few larger fires are used. The explanation of these experiences is found in the phenomenon of temperature inversion. Since the coldest air is near the surface, when air is heated it will rise (being cooled as it rises) only to a height where the air temperature is the same as that of the heated air when it reaches that height. Thus, let us assume that the temperature in the orchard is at an elevation of five feet, 27° F., ten feet, 29° F., fifteen feet, 31° F., twenty feet, 34° F., twenty-five feet, 36° F., and at thirty feet, 37° F. If, by use of many small fires the temperature in the orchard is maintained evenly at 31° F., since the air cools in rising, the heaters would be warming the air to a height of less than fifteen feet. However, since the air temperature immediately above the heaters may be several degrees above that farthest from the heaters, some air would be hot enough to rise considerably higher than fifteen feet. Of course, when air rises above this 31° F. level, heat is being wasted. This explains why to use many small heaters is more economical than to use fewer large heaters. With the large heaters much air is heated to a temperature considerably above that necessary and heat is wasted in warming upper strata of air.

It should be emphasized that the above example is of a possible but not of a typical cold night. Generally, the rise in temperature with increasing elevation would be less rapid. With a surface temperature of 27° F., the temperature at an elevation of forty feet might not be above 31° F.; and much more heat would be required to warm the orchard four degrees. During a windy night with little temperature inversion the difficulty of heating the orchard may be very great. The trees, however, tend to prevent the warm air from being blown out of the orchard. During such a night, in fact during any night, it is easier to heat an orchard than to heat a vineyard or a strawberry planting. Unless the rise in temperature with increasing elevation is very rapid, the only way a strawberry planting can be protected by heating is by using small fires close together, perhaps five hundred to one thousand to an acre.

It is possible to heat the orchard with coal heaters, but the process is laborious; and in order to obtain enough heat when needed they must be started before it is possible to know what the temperature is likely to be. The heaters in use are mainly pots in which low-priced oil is burned. Sometimes there is an arrangement for varying the amount of burning surface. When it was thought that the effect of the smoke formed was important in preventing heat loss by radiation, wide-mouthed pots, with which the combustion was very imperfect and the amount of smoke formed very large, were considered satisfactory. However, now, since it is known that the amount of heat radiated into the orchard is the important consideration, heaters with metal pipes or chimneys about two feet high are used. Combustion of the oil should thus be more complete; and these chimneys, of course, become very hot and radiate heat outward into the orchard. Probably by this means the heated air is distributed more widely around the heater, the temperature directly above not being as high as it would be without the chimney. The amount of heat escaping into upper air strata should thus be reduced. In California citrus orchards, it seems to be the experience that considerably better results are obtained if the chimneys are large, say five or six inches in diameter, than if they are smaller. Increasing the diameter of the chimney, of course, increases the radiating surface.

Naturally the oil cannot be bought and placed in the heaters in the orchard during the night when the killing temperature is liable to prevail. There must be equipment for storing the oil and an oil supply large enough for several heatings. In fact, generally the heaters must be filled and kept in the orchard throughout the period when there is danger of killing. The cost of the annual labor and the depreciation of the heaters and of other equipment is, therefore, rather large. Further, since it is not possible to know precisely what minimum temperature may be reached or what temperature the tissue at a particular time may withstand, the orchard must be heated in a considerable number of nights during which heating will later be found to have been unnecessary. Coit (973) gives an estimate, made by a grower, of the annual cost of heating a large lemon orchard in California. The value of equipment, including reserve oil for five hundred acres, was $91,225.92, and the annual cost to the acre, including estimated depreciation on equipment, was $33.34. Young (1179a) gives a record for one lemon orchard in which the average annual cost to the acre of heating during the six years, 1913 to 1918, was $78.90; in another the average annual cost to the acre from 1913 to 1917 was $26.55. With the present price level it would probably be $50 to the acre or more. It is evident that the cost is too great for the practice ever to be used widely in deciduous fruit orchards. If one crop in ten years should be saved, the cost for heating would be $333.40 or more. Of course, the crop is seldom or never worth that much in early summer, before spraying and harvesting expenses have been incurred. And it is probably the exceptional section in which more than one crop in ten would be saved. It is doubtful if in New York and New England one full crop in thirty years would be saved by heating.

With citrus fruits the conditions are different. A freeze may injure not merely blossoms, but also fruit that may be ready to harvest. Even the trees may be so seriously damaged that the crop for several succeeding years may be reduced. It is probable that only with subtropical fruits, grown where there is danger of occasional freezes, and a few deciduous kinds, such as the apricot, where a freeze in one locality may appreciably reduce the total crop and increase the price for the whole country, will orchard heating come to be practiced extensively.

There has been discussion popularly of the possibility of getting the warmer air from above down into the orchard. Miss Baker (934) reports the patenting of a device for drawing the warmer air down through pipes to be discharged into the orchard, thus mixing with and warming the cold air. Of course if such a device could be made to work it would save the crop only during freezes when there is large inversion of temperature. We have seen that there are freezes particularly during windy nights, but sometimes when there is little wind, when the air temperature above the orchard is but slightly, if any, warmer than that in the orchard.

Summary. During a still clear night, heat is radiated rapidly from the earth's surface and from bodies upon it, and the air by coming into contact with such cooled surfaces is cooled. Cold air may, also, be brought into a section by means of winds. Tissue, such as leaves and blossoms, may, during still clear nights, be cooled by radiation and by evaporation to temperatures below that of the neighboring air — but we do not know that, after ice formation begins and heat is being thus liberated, tissue containing much water is at a temperature much below that of the air. The tissue of trees in winter does not seem to be below that of the air; and just beneath the bark of large tree trunks, the temperature tends to lag behind that of the air. The cooling of the air that comes in contact with the earth during still clear nights, which are favorable for radiation, causes temperature inversion, the temperature of the air being low next to the earth and increasing upward for some distance. At the top of this layer of cold air is a thermal belt, above and below which the temperature is lower. The thermal belt is at a lower elevation on a single mountain or hill rising out of a plain than on the side of a mountain facing another mountain. Air drainage, the replacement of the air cooled by contact with the hillside by the warmer free air, is much more effective on a rather steep than on a gentle slope. Windbreaks are sometimes beneficial by lifting a cold wind over a section warmed by a body of water or a cold ocean wind over a section being warmed by sunlight and by lifting the wind and thus preventing the soil from becoming cold enough for the roots to be killed. On the other hand, windbreaks, by impeding the replacement of cold air with the adjacent warm free air, may, during rather still clear nights, cause the air to be colder in the area over which the wind is lifted. During a still clear night the air may be the warmest on the hill slope that is reached by what wind is blowing; this because of the more rapid replacement of cold surface air with the warmer free air.

In the northern hemisphere, the soil on the south slope receives the most nearly direct sunlight and becomes warmer during the day. Low growing plants, such as strawberries, will develop more rapidly during the spring on such a slope. Trees on the north slope may receive as nearly direct sunlight as trees on the south slope; and may bloom as early unless the steepness of the hill, the planting distance and the size of the trees are such that, during part of the day, a shadow is thrown on the trees on the north slope, by the hill itself or by the trees above.

An orchard located so that, during cold nights, it receives a wind that has passed over a large body of unfrozen water is in less danger than others from autumn, winter or spring freezes. However, with rather small bodies of water, the influence on the temperature of a neighboring orchard may be complicated by shifts in the direction of the wind, by cold air from surrounding hills and perhaps by other features. The time of blooming can be delayed by mulching only when the entire plant is covered. In a sunny section, blooming may sometimes be delayed by keeping the twigs whitewashed; but it is doubtful if the amount of fruit saved during a long period would justify the expenditure.

Covering the orchard with smoke seems to have little influence on the temperature unless heat is given out into the orchard. Orchard heating is more effective when the low temperature in the orchard is due to local radiation and there is rather rapid rise in temperature with increasing elevation. Under such conditions, heated air may not rise much above the orchard. The larger and hotter the individual fires the more heat is wasted in warmer air strata above the orchard; and the most effective heaters seem to be those with chimneys which radiate heat horizontally into the surrounding air.

CHAPTER 24

CLIMATIC RESPONSES OF THE DIFFERENT KINDS OF FRUITING PLANTS

In previous chapters the responses peculiar to given species and varieties were discussed only when necessary to emphasize principles of climatic response. Since not all of the fruits have the same climatic limitations it is necessary to discuss the behavior of each.

The apple. The apple is among the most widely distributed of fruits. Not only does it show rather great resistance to heat and cold, but it is rather strikingly resistant to drought. Goff (436) says that, during the summers of 1894 and 1895 in western Wisconsin, established apple trees were uninjured, many bearing good crops, yet so serious was the drought that many forest trees, including red oak and hard maple, were killed.

Varieties of apples may be found fruiting at latitudes as low as 30° or 31°, even when the altitude is below 1000 feet. They are said to fruit reasonably well at Mexico City at latitude about 19° and altitude about 7400 feet. Mr. Alvera Rebolledo, Colombian consul at San Francisco, tells me that in Colombia, at latitude about 3° and altitude about 3500 feet, apple trees are seldom seen, but that he has observed a few trees to bloom heavily about three times a year; all of the blossoms falling without setting fruit. However, he says that, at about that latitude where the altitude is about 5500 to 7000 feet, apple growing, at least in home plantings, is not uncommon, and the trees set crops of fruits that reach good size and have excellent quality. He does not know how many times in the year or at what times the trees bloom or how many crops are borne. It does not seem that at such a latitude there could be a distinct chilling period to cause the ending of a rest period; and there is no appreciable variation in the length of daily illumination. It would be interesting to learn how the time of formation of fruit buds and of blooming is determined. Except at rather high elevations the apple is not grown commercially at as low latitudes as the peach. Below a latitude of about 34°, unless the elevation is rather high (considerably over 1000 feet) apple trees do not seem to fruit well, though in California, Arizona, and New Mexico they are grown very successfully at latitude 33° or lower, when the elevation is several thousand feet. I have never found a careful description of the behavior of apple trees at rather low latitudes and altitudes, but it seems that trees (at least while young) may make healthy growth, but do not set fruit. As to whether this failure to set fruit is due to the fact that the winters are too short for the trees normally to end their rest periods, or is due to excessive summer heat, we can hardly be certain. The experience in Colombia suggests that summer heat is more influential than lack of winter chilling in causing the failure to fruit. It suggests, also, that unfruitfulness is not due to a failure to form fruit buds.

McClatchie and Coit (1076) say that in Arizona at elevations below 3000 feet the climate is too hot for the tree and for the fruit, and that if fruit is set it is of very low quality. In most of the interior valleys of California, even at latitudes as high as 40°, the fruit is of low quality because of the heat; though the trees may grow reasonably well, set fruit buds, and bloom normally. Early summer apples may be of fair quality and are not generally burned by the sun; though late apples may be burned on the sunny side before early apples are off the trees. It seems that as the fruit approaches maturity, it becomes more resistant to the high temperature and the intense sunlight that cause the killing in the sunny side. We have seen, in Chapter 20, however, that high temperature may cause the development of low quality even when there is no killing of tissue; and that the color developed may also be influenced by the summer temperature. In California the fruit of Delicious seems to develop more nearly normal quality, in the hot valleys, than does that of many other varieties.

Shaw (1341) seemed to find that the temperature in early summer may influence the form of the fruit. It is well known that apples growing in different sections vary greatly in form, those from some sections, such as Nova Scotia, the northwestern part of the United States and western Canada being much more elongated than those from other sections, such as part of the Mississippi Valley. Shaw tried to find differences in climate among these sections that would explain the difference in form. With the Ben Davis apple a study of the temperatures of the different sections during the later parts of the seasons failed to show any differences corresponding to the differences in form. On the other hand, temperature differences for the different sections during the two or three weeks following the bloom seemed to show marked correlation with the differences in form. The same was true of the differences in form for the different years at Amherst, Massachusetts. The cooler the weather during these two or three weeks the more oblong in form were the apples.

It seems desirable again to give a brief summary of the conclusions of Shaw (1341) as to the relation of the mean summer temperature to the quality and color of the fruit of different varieties. By mean summer temperature, he means the temperature for the period from March 1st to September 30th. As to whether or not this is the best period to use, we cannot say. He seemed to find that a difference of two degrees Fahrenheit in the mean summer temperature will be enough to cause perceptible differences in the color and the quality of some varieties; particularly with varieties ripening late in the season. Less difference was shown with summer varieties, which are adapted to a wider climatic range. From having examined a considerable number of samples from the different sections, he concluded that growing a variety in a section with a mean summer temperature lower than that to which it is best adapted results in greater acidity, a higher content of insoluble solids, greater astringency, less coloration, decreased size, and scalding in storage (conditions indicating immaturity). On the other hand, growing a variety where the mean summer temperature is higher than that to which the variety is best adapted, results in uneven ripening, premature dropping, rotting on the tree, poor keeping quality, lack of flavor, mealiness, less intense color, and smaller size. Some of these influences, such as poor keeping quality and mealiness, may result from a more advanced stage of ripeness when picked and some, such as smaller size and less intense color, may be a result of a limited water supply or of some other influence besides heat. However, we can hardly say that heat alone might not cause reduced size and less intense color. It seems that the other influences can be explained only by the injurious effect of the heat on the tree or fruit. In Table 67 are given some of the varieties studied by Shaw and the mean summer temperatures which he considered most favorable for the development of high quality.

Some of these varieties are not widely grown and it would not be possible to obtain such a number of specimens that determinations could be sufficiently accurate to place such a variety in a given class with certainty. From experience, it seems almost certain that for the development of best quality, McIntosh requires a lower summer temperature than Baldwin. In fact, it seems doubtful if with many of these varieties we can be certain that a summer temperature a little higher or a little lower might not be as favorable. The nature of the soil has much to do with the color and quality of the fruit; and so, to determine so minutely the most desirable summer temperature, it would seem that only fruits from soils much alike in texture, if not in chemical composition, should be used. It would seem remarkable, too, if with every variety, a mean summer temperature a little too high for the development of the best quality would also be too high for the development of the best color. Further, it seems possible, if

TABLE 67. MEAN SUMMER TEMPERATURE FAVORABLE FOR THE DEVELOPMENT OF THE BEST COLOR AND QUALITY IN APPLES

VARIETY	MEAN TEMPERATURE
Hibernal, Oldenburg	52° F.
Pewaukee, Yellow Transparent	53° F.
Alexander, Blue Pearmain, Red Astrachan, St. Lawrence, Wolf River, Fameuse	54° F.
McMahon, Northwestern Greening, Ribston, Mann, Salome	55° F.
Baldwin, Early Harvest, McIntosh, Northern Spy, Ontario, Rhode Island Greening, Tompkins King, Wealthy	56° F.
Chenango, Hubbardston, Roxbury, Williams	57° F.
Early Strawberry, Red June, Twenty Ounce, Winter Banana	58° F.
Benoni, Delicious, Esopus, Jonathan, Red Canada, Wagener	59° F.
Cooper Market, Rambo, Rome Beauty, Green Newtown	60° F.
Maiden Blush, Yellow Bellflower	61° F.
Akin, Grimes Golden, Ingram, Ralls, White Pearmain, York Imperial	62° F.
Arkansas Black, Fanny, Stayman	63° F.
Ben Davis, Willow Twig, Winesap	64° F.
Arkansas, Bonum	65° F.
Horse, Limbertwig, Shockley	66° F.
Terry, Yates	67° F.

not probable, that the effect of the mean summer temperature on quality may be due to its effect on the time of ripening; a high mean temperature for the period from April to October, causing the fruit to go through its later development and its ripening process earlier in summer or autumn when it is still rather hot. However, while the fine discriminations of the table may not be justified, we can be reasonably certain that the varieties toward the top of the table are adapted to a low mean summer temperature, and those toward the bottom to a high mean summer temperature. Some of the early ripening varieties such as Red June, Benoni and Yellow Transparent may be much less dependent upon the mean summer temperature than upon the temperature about the ripening time.

Winslow (1176) thinks that in the fruit-growing districts in the northwestern part of the United States and the southwestern part of Canada, the summer temperature and the length of the growing season are influential in determining the size of the fruit; Jonathan, for example, being smaller in the cooler sections with the shorter growing seasons. Naturally, if the season were too short for the variety to reach proper maturity, such a result might be expected. However, in most cases where the season is not extremely short, the soil moisture and nitrogen supply, the heaviness of the crop, the age of the trees, the water supply and the amount of renewal pruning will be more influential than the summer temperature in determining size of fruit.

Certainly the quality of some varieties is influenced strikingly by the summer temperature in which the fruit develops, and particularly that in which it ripens. Thus, Grimes Golden develops in New York little of the characteristic flavor which it develops at lower latitudes; and Macoun (1069) says that the Delicious apple is one that requires much heat to bring out its characteristic high flavor. McIntosh and Fameuse are striking examples of varieties which require rather low summer temperature to bring out the best flavor. Thus, both of these varieties develop considerably better flavor in Vermont, northeastern New York, or Canada than they develop a little farther south, except at considerable altitudes. High summer temperature seems more strikingly to inhibit the development of high quality with Fameuse than with McIntosh; but I know of no evidence that a summer temperature below what Shaw lists as the optimum for these varieties causes a greater reduction in quality with one than with the other. In fact, both seem to develop high quality as far north in Canada as the trees can be grown without much winter injury to the wood.

Some varieties of apples can be grown and ripened reasonably well when the summer temperature is too low for the proper ripening of most other fruits. At Watsonville, California, the growing season is very long; but, because of the wind from the ocean, the temperature is rather low; the mean from April 1st to September 30th being about 60.5° F., and the highest monthly mean being 63.3° for July. And, due to fogginess, the temperature of the fruit is not above that of the air during as much of the time as in sunny climates. Some varieties of apples do very well in that district; though other fruits, unless it be some varieties of pears, do not develop normal flavor. We shall see in Chapter 26 that even with the leading variety of apples grown, the Green Newtown, the low temperature at ripening time seems to cause the development, while the apples are in storage, of a rather serious browning of the tissue. In such low summer temperatures, apple trees seem to make better growth than do pear trees and the trees of some other kinds.

A variety that reaches its best flavor in a rather low summer temperature may not be one of which the wood will withstand the lowest winter temperature. Shaw gives 56° F. as the best mean summer temperature for Baldwin and Tompkins King. Except in coastal regions, or at high elevations at low latitudes, such a summer temperature would prevail only where rather low winter temperatures would be expected. Yet, the wood of these two varieties is less resistant than that of nearly all, if not all, other varieties. On the other hand, Delicious develops high quality in northern Mississippi, and yet, the wood resists the winter temperatures of northeastern New York and of Vermont. To be grown at a high latitude a variety must not only be one of which the fruit will ripen and acquire normal quality in a short growing season with rather low summer temperature; but, unless there is winter protection furnished by a large body of water or by some other influence, it must also be one of which the wood will become hardened during a rather short growing season, and will withstand a rather low winter temperature. Information as to the different ways in which the wood may be injured has been given in Chapter 22. In this discussion, we are concerned with any kind of sapwood bark or cambium injury that weakens or kills the tree.

Only a few of the less important fruits, such as gooseberries and currants and some American species of plums, can be grown at higher latitudes than can some varieties of apples. Macoun (1063) reports that hybrids between *Pyrus Malus* and *Pyrus baccata* have fruited at 58° north latitude. The wood of certain varieties of *Pyrus Malus*, known as Russian varieties, is very resistant to low winter temperature. Most of these ripen in summer or early winter in the southern part of Canada, though farther north some of them will keep late into the winter. Perhaps the hardiest of these Russian apples is Hibernal. The best known and most widely planted are Yellow Transparent and Oldenburg, the latter being the hardiest. Other varieties with resistant wood, probably from Russian sources, have originated in North America; and a few, such as McIntosh and Fameuse, not from Russian sources, are very hardy. Yet, *Pyrus baccata* seems to be the most hardy of apple species; Wealthy is supposed to be a seedling of the Cherry crab (*Pyrus baccata* x?) and is very hardy; but, under some conditions at least, less so than McIntosh.

In New York, during the winter of 1917–18, no McIntosh trees were injured, in so far as I was able to learn; while a considerable number of Wealthy trees were killed completely or were badly injured. Yet, horticulturists of Minnesota insist that in that State Wealthy is more resistant than McIntosh. In New York, young non-bearing Wealthy trees are as resistant as young non-bearing McIntosh trees; it may be that in Minnesota the seasons are not as favorable as in New York for the hardening of the wood of young late growing trees; and McIntosh tends to grow later than does Wealthy. The injury in New York during the winter of 1917–18 was to trees that had borne a very heavy crop in the summer of 1917. McIntosh seldom bears such excessively heavy crops, relative to the size of the tree, as Wealthy often bears. Fameuse seems less hardy than McIntosh. Among the varieties with least resistant wood are Baldwin, Tompkins King, Stayman, Gravenstein, Rhode Island Greening, Hubbardston, and Winter Banana. Not the same order of hardiness will be shown during different cold winters or in different sections. In New York, during the winter of 1917–18, there was much less injury to Baldwin trees than there probably would have been if 1917 had not been the "off year" for most old Baldwin trees in that State; and there was greater injury in northwestern Massachusetts because 1917 was the bearing year. Hubbardston trees like Wealthy trees were less resistant because of their having borne a heavy crop the summer of 1917. Northern Spy is considerably less resistant in wood than is McIntosh. It may be classed as medium hardy as with Twenty Ounce, Grimes Golden and Red Canada; slightly less resistant is Jonathan and still less are Esopus, Fall Pippin, and, possibly, Roxbury. Delicious seems to be more resistant than Northern Spy; but experience has not yet indicated how much more. It is interesting that Baldwin, Rhode Island Greening and Tompkins King, all varieties grown but little in the lower latitudes, are less resistant than Winesap, Stayman, Arkansas, Red June, Virginia Beauty, and a number of other varieties grown generally at lower latitudes.

As to how much of the difference in hardiness of different varieties is due to a difference in rate of maturing of the wood it is not easy to learn. Baldwin, one of the least resistant, generally holds its leaves the latest of the varieties grown in New York, and Rhode Island Greening also matures late, though Tompkins King, a very tender variety, does not seem to be late in maturing. It is probable that few varieties reach their maximum resistance during the average growing season in the climate of New York, certainly not during the shorter growing seasons such as that of 1917. Ben Davis, grown in Missouri or southern Iowa, where the growing seasons are longer and hotter than in New York, often is uninjured by a temperature considerably lower than that which killed Ben Davis trees in parts of New York in 1917–18.

In the climate of the northeastern part of the United States apple trees younger than about eight years of age, at least in the years when the growing seasons are shortest, reach greater hardiness if the summer's growth is not very vigorous. This does not seem to be true of older trees. Thus, during the winter of 1917–18, the most resistant trees, particularly of Baldwin, seemed to be those about fifteen to twenty-five years of age that had made a vigorous growth and had not fruited during the summer of 1917. It is possible that at the highest latitudes at which apple trees are grown, some care to reduce vigor of growth and thus to hasten maturity of the wood of apple trees during the first six or eight years in the orchard, may be wise, but in most sections of the United States it is seldom, if ever, advisable to reduce growth for any possible slight increase in hardiness.

With most varieties of apples the most common injury is in the sapwood. With old trees that are declining in vigor, rather severe injury to the sapwood, even when there is little or no bark or cambium injury, may result in death. However, vigorous trees even when nearly all sapwood is killed will generally recover if the cambium has not been killed, and if a good supply of nitrogen is available early in the season. In New York, following the winter of 1917–18, in orchards ploughed very early in spring, trees generally recovered, even when the injury to the sapwood was so great that the leaves in the summer of 1918 were not more than fifteen to twenty-five per cent of their normal size and no twig growth was made early in the summer. In one orchard, in a very cold section, trees about fifty years old, which early in the summer of 1918 seemed too badly injured to recover, had within three years become good trees. This orchard was ploughed in the fall of 1917 and of 1918, a good supply of available nitrogen early in the season being thus assured. The recovery from such injury is generally most rapid in the lower parts of the tree. In well-cultivated orchards, usually about midsummer after a winter causing such injury,

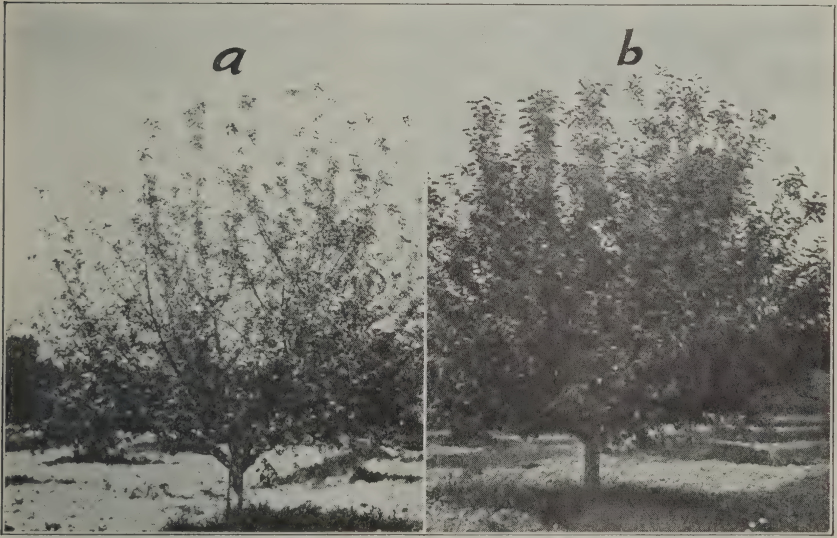

FIGURE 57. Baldwin apple tree, *a*, August, 1918, showing weak growth following severe injury in the sapwood; *b*, same tree in the summer of 1919. In both years the most rapid recovery was in the lower branches.

water sprouts will begin to grow from the lower parts of the branches; and second growth may start from the twigs of lower branches. During the second summer after the injury there will generally be many water sprouts and the twigs on the lower branches will be much the longer. (The normal way is for the twigs in the upper part of the tree to be the longest.) It seems that with apple trees a new layer of healthy sapwood forms more rapidly low on the tree.

In nurseries where the winters are very cold, trees of tender varieties such as Baldwin and Stayman are often injured in the sapwood. When such trees are transplanted in the spring after a severe winter they seldom make a satisfactory growth and may die. Such "black heart" trees are worth much less than nothing because there will be expense of planting and of a summer's care. If, however, they stand in the nursery and have good care during the summer after the injury, they form a new layer of sapwood and generally transplant satisfactorily. In nurseries at latitudes as high as that of New York, trees of the more tender varieties, to be sold in the spring, should be dug in the fall and kept in a storehouse.

Bark injury is especially common with the apple, and the form known as "crotch injury" is more often found with the apple than with other fruits. Usually trees from about five to fifteen years of age suffer most from this form of injury. Trees will be the most liable to be so injured if they have a number of branches of nearly equal size, starting from nearly the same level and growing upright in such a way that the inner secondary branches are shaded off. The Northern Spy variety has commonly such a branching system, and is one of the most susceptible to this form of injury. Trees with a central leader, all of the branches being considerably smaller than the leader, seem less liable than others to be injured in this way. In fruit-growing districts where the winters are severe, it might be wise to train susceptible varieties such as Northern Spy, to this form. With Northern Spy there is often crotch injury when the tree is otherwise uninjured, the sapwood not being injured enough to cause a weak twig growth in the summer following the cold winter. Even when the sapwood is not injured, the unions are weak and, because of the very slow healing, the union does not increase in strength as rapidly as the branch increases in size and in amount of fruit borne. Northern Spy branches which are not braced are almost certain to be broken by the first heavy crop borne while there is unhealed crotch injury. Crotch wounds heal so slowly that in New York during the first three years after the cold winter of 1917–18, it looked as if any branch with a rather large crotch injury would ultimately be worthless. However, by the summer of 1921 it became evident that branches well braced and on which such wounds had been kept painted would eventually form strong unions with the trunk; the wounds gradually being covered as shown in Figure 58. The wound originally extended downward and outward to a line indicated on one side by the knife; and, partly by callous growth but mainly by growth of the upper side of the branches, it is nearly covered. Thus, a strong union with the trunk is being formed. The top of the wound will eventually be covered by the pressing together of new wood of the trunk and of the branch.

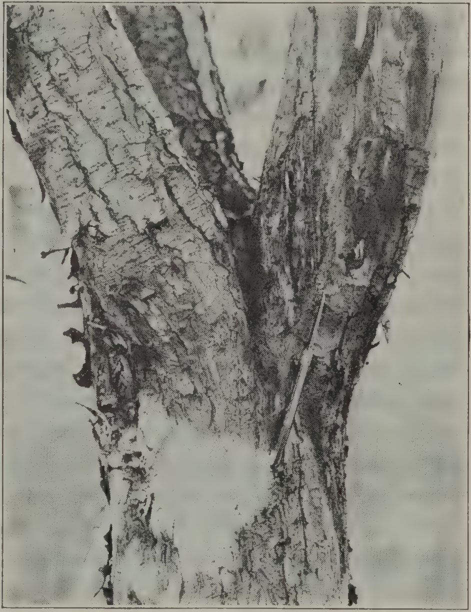

FIGURE 58. Crotch wound not fully covered five years after severe winter. The knife indicates the original border of the wound, which is being slowly covered not by callous growth, but by gradual enlargement and coming together of the branches.

Loss from root freezing is greater with apples than with most other fruits. This is primarily because the apple is grown in colder regions where the soil freezes deeper, the roots being but little more resistant than those of the peach or other kinds with more tender wood. Methods of avoiding root injury have been discussed in Chapters 6 and 21.

The killing of the blossoms or opening fruit buds of the apple is more complicated than that of the peach. The fully open blossom is generally less resistant than that of the peach. The killing temperature of fully open apple blossoms will seldom be lower than 25° F.; and 28° F. often kills them. Then, under some conditions of growth, the opening buds of the apple, before any petals are showing, but when the flowers are still sticking together in the cluster, may be nearly as tender as the open blossoms. Even when the flower parts are still enclosed by the leaves of the opening buds they may be rather easily killed. At Ithaca, New York, in the spring of 1921, the buds were much further advanced than usual by March 29, when the temperature fell to 14° F. in the Cornell Experiment Station orchard. Nearly all varieties (except those blooming very late, such as Northern Spy) had more than fifty per cent of the spur bloom killed; and a number of common varieties such as Twenty Ounce, Hubbardston, McIntosh and Wealthy had ninety per cent or more killed. Buds of both peaches and pears were in a more advanced stage of development and yet suffered much less injury. The injury in the opening apple buds was not evident until some time after the freeze. The unopened flowers seemed to dry up, due to the death of supporting tissue back of them. Sometimes only the central flower of the cluster, the one most advanced in development, was killed. Similar killing, though less serious, was observed with buds of the apple in about the same stage of development following temperatures of 18° to 20° F. on April 21, 1922. With apple flowers, the reduction in hardiness with advance in development is not always as uniform as with peach flowers; and there seems much less difference in resistance between the time just before the petals begin to show through the calyx and when the fruit is one half inch in diameter. In latitudes so high that apple trees tend to bloom nearly as late as peach trees bloom, the loss from late spring freezes seems to be as great with the apple as with the peach, or a little greater.

There is more difference in time of blooming of different varieties of apples than with most other fruits and the possibility of breeding late blooming varieties for climates where late spring freezes are common seems greater than with most fruits. Some late blooming varieties are Ralls, Ingram, Schoharie, Red Canada, Northern Spy, and Rome Beauty. Varieties such as Wealthy and Wagener have late opening flowers from axillary buds.

The blossoms and young fruit of some varieties are more resistant than those of others even when in the same stage of development. Few if any varieties bloom earlier than Oldenburg; yet, a good crop of this variety has been left by freezes that killed nearly all the bloom or young fruit of other varieties that bloom at the same time, or even a little later. Benoni, Yellow Transparent, Wealthy, and Rome Beauty also seem to have blossoms and young fruit that are a little more resistant than the average. The mature fruit of the apple is sometimes injured by freezing before harvesting late in autumn. It is considerably more resistant to freezing, however, than are the mature fruits of most other kinds. The freezing temperatures of harvested fruits will be discussed under storage problems in Chapter 26. The apple tree seems to have the longest rest period of any of the tree fruits, varieties such as Grimes Golden blooming in southern California in May, nearly as late as in New York. Yet in that section almonds bloom in February and apricots will be three fourths of an inch in diameter by April 10.

The pear. In humid regions the pear is not generally grown at as low latitudes as the apple. This is not because of a direct effect of climate on the tree, but is because the "pear blight" organism (*Bacillus amylovorus*) is more destructive at high temperatures.

In dry sections the pear is grown where the summers are too hot for the fruit of the apple. Dr. W. L. Howard says in a letter that pears, particularly the Bartlett, seem to reach their best development in the hottest part of the Sacramento Valley. Apparently both fruit and tree of the pear reach their best development at a rather high summer temperature. Some varieties such as Bosc will not reach high quality if ripened at a low temperature. However, Anjou, Comice, Winter Nellis, Howell, Hardy, and a number of other varieties not so well known seem to develop excellent quality in the low summer temperature of coastal sections of California and sections around the San Francisco Bay; and in slightly warmer sections all varieties seem to develop high quality. The trees seem to grow less rapidly than in the warmer valleys; but because of the low summer temperature there seems to be little if any danger from pear blight in the coastal counties of California, Oregon, and Washington.

Trees of most pear varieties are less resistant to winter freezing than are those of most apple varieties; and no pear variety can be grown at as high latitudes as can the most resistant apple varieties. Among the more hardy varieties are Flemish Beauty, Anjou, and Clapp Favorite. Trees of the first two of these varieties seem to be as resistant as the trees of Northern Spy apples or slightly more resistant, and are in much less danger of crotch injury. Among the least resistant varieties grown in the northeastern part of the United States are Bartlett and Bosc. These are less resistant than Baldwin or Tompkins King apple trees, but are generally more resistant than peach trees; Seckel and Clairgeau are but slightly more resistant than Bosc, and Sheldon approaches Clapp Favorite in resistance. Kieffer, thought to be a *Pyrus communis*, *Pyrus serotina* hybrid, is, under some conditions, more resistant than Bartlett and under others less resistant. It seems to require a longer period for ripening the wood than most other varieties require. Like the apple, the pear shows great ability to recover from almost complete killing of the sapwood.

Pear spurs bearing fruit often form a very thick woody growth back of the fruit stem. Such wood is tender and may be killed during even a rather mild winter. The sapwood of the pear spur is generally less resistant than the other sapwood of the tree.

The blossoms and young fruit of the pear seem more resistant to freezing than are those of the apple. Thus, in the spring of 1921 at Ithaca, New York, many opening buds, flowers or young fruit of the apple were killed by freezes on March 29th, April 11th, and May 17th. The time of full bloom of the pear ranged from April 24th to April 27th and of the apple from April 27th to May 1st; yet, nearly all varieties of pears bore a rather heavy crop; while only a few varieties of apples bore more than a very small percentage of a crop. Many pear fruits were one third of an inch in diameter when the last freeze came. They were frozen solid, but while many seeds were killed the other tissue was uninjured and developed normally; many seedless fruits being harvested.

Sometimes surface tissue of young apples and pears is killed in such positions that, as the fruit grows, wide or narrow rings of corky tissue, called frost marks, may be developed on the surface.

In New York where the winters are long, the pear blooms early relative to other kinds of fruit; generally as early as the peach or earlier, and as early as other stone fruits except sweet cherries and some varieties of plums. Yet McClatchie and Coit (1076) say that in Arizona the pear blooms late as compared with stone fruits. In California, the pear generally blooms about ten days to two weeks later than such varieties of peaches as Elberta, though in some seasons there is little difference. Pears as well as peaches are generally in bloom during a longer period in California than in New York. This later blooming and slower opening of the bloom in sections with short mild winters seems to be due to a long rest period; which is only partly ended when blooming begins. In California, particularly in the southern part where the winters are the shortest and the warmest, the pear behaves during blooming as if it were still partly in the rest period. Following warm dry winters such as that of 1923–24 in the warmest sections it may not bloom or start growth until late in May, though January and February weather was warm enough for blooming if the trees had not been in the rest. Although the pear seems to have a rather long rest period it is said to fruit in Colombia at latitude 3°, at elevations somewhat higher than 3500 feet. It does not seem that there could be during the year a distinct chilling period to break the rest. It seems barely possible that at the rather low temperature of high altitudes the rest period may be less pronounced.

According to Müller-Thurgau (1089) the ripe fruits of the pear are a little less resistant to freezing than are those of the apple. Observation in the orchard suggests that fruits of Kieffer are more resistant than are fruits of many varieties of apples. Since varieties differ as to resistance, it is possible that fruits of many of the pear varieties not tested by Müller-Thurgau may be as resistant as fruits of the average apple variety.

The quince. The commercial culture of the quince, except in dry valleys in the western part of the United States, tends to be confined to sections where the summers are cool and the winter temperatures not extremely low. This is probably because of its susceptibility to Fire Blight (*Bacillus amylovorus*) where the air is hot and humid. The tree itself and its fruit seem to be very resistant to high summer temperatures; the fruit seems to reach its best development in Asia Minor, where the summer temperatures are very high. It does especially well also in the hot valleys of California. In those sections the dryness of the air inhibits the spread of Fire Blight.

The resistance to low temperature of the wood of the quince is generally a little greater than that of the peach and perhaps a little less than that of the Bartlett pear. Sometimes, however, a greater percentage of quince trees than of peach trees will die as a result of a severe winter. The quince tree is less vigorous in growth than the peach and seems to have less ability to recover from equally severe injury.

The quince is a late blooming tree and sometimes the blossoms escape injury from spring freezes that kill the blossoms of other kinds. However, the young opening shoots, on which the flowers are borne terminally, are, under some spring conditions, very tender. Since the growth of these shoots begins rather early, they are sometimes killed, and the quince crop thus destroyed by spring freezes that do little injury to peach and pear buds or blossoms. At least this is true sometimes in the climate of New York. In sections with long winters the quince blooms later than other tree fruits. However, in California it blooms earlier than the pear and as early as the average sweet cherry variety, or earlier, its rest period apparently being rather short.

The peach. The peach tree and fruit withstand rather high summer temperature. The quality of the fruit of some varieties, usually those with the highest acidity, may be improved by such high temperature; while the fruit of others, usually those of mild flavor, may be rendered more insipid by growing at high temperature. The average peach variety fruits well at latitudes too low for good fruiting of most apple varieties. Well-known varieties, such as Elberta, Carman, Hiley, and Belle, fruit reasonably well at latitudes as low as 31° or a little lower. However, with nearly all such varieties, the quality of the fruit is reduced by the high temperature of such latitudes unless the summer temperature is lowered by the influence of a body of water or of high altitude. There are groups of varieties such as the Honey group, the Peen-to group and the Indian or Spanish group, of which the fruit reaches normal quality at such latitudes and even at lower latitudes; and of which the trees withstand the conditions and fruit normally at latitudes as low as 27° or 28° when the altitude is as low as 1000 feet or lower. At latitudes as low as 3° in Colombia, according to Mr. Rebolledo, peaches of high quality are grown at altitudes from 3500 to perhaps 7500 feet.

It was shown in Chapter 20 that at lower latitudes the initial spring growth of peaches is weaker than at higher latitudes, the amount of leaf growth when the bloom falls being considerably less at the lower latitudes. At latitude 31, unless the altitude is high, in some springs blossoms of such varieties of peaches as Elberta open very slowly, some drying up and falling off before being fully open. The leaf buds open even more slowly, there being little leaf growth when the trees are in full bloom. In Southern California in the summer of 1924, following a warm dry winter, many peach trees of common varieties did not bloom or start growth until nearly June 1st. The bloom and leaf buds of such groups as the Spanish and the Honey, however, open more nearly normally; both considerably earlier than with Elberta or other common varieties. Yet, at higher latitudes there is not this difference in blooming or leaf opening time. It seems probable that the rest period of such varieties as the Spanish and the Honey group is shorter than with most varieties. It would seem that in Colombia, except at elevations so high that the summers would be too cool to ripen the fruit, there would be no chilling period to bring about the normal ending of the rest period. As to whether or not the varieties grown there are of these types with very slight rest periods, I do not know. It was formerly thought that these varieties, at least the Honey group, could be grown only at low latitudes, but Hedrick *et al.* (165) reports that several varieties of the Honey group withstand the climate of Geneva, New York (latitude 43°).

The fruit of the peach does not ripen as well as that of the apple in a low summer temperature. Thus, in England, few if any peach varieties can be ripened except against walls, while many varieties of apple are ripened well. And, in so far as I am informed, no varieties of peaches are ripened even on walls in Denmark or in southern Sweden; though a considerable number of varieties of apples ripen, and, due to the influence of the Gulf Stream, the winter temperature is more mild than that of peach-growing sections in the northeastern part of the United States. In fact, in much of the northwestern part of Europe, the limiting climatic influence for peach growing is the low summer temperature rather than low winter temperature. Of course, with trees holding fruit late into the autumn, the wood might be so poorly hardened during such a short growing season, that it would be killed by even rather mild winters.

The wood of the peach is more tender than that of the apple; but, at least with young trees, it may reach its maximum condition of hardiness in shorter seasons than will the wood of some varieties of apples. Thus, wood of young peach trees seems to withstand fully as low temperatures in New York as in Missouri; while wood of the Ben Davis apple will withstand considerably lower temperatures in Missouri than in some winters in New York. And Professor R. W. Reese has told me that, in some studies with fruit trees on Cape Cod in Massachusetts, peach trees survived the winters better than did Baldwin apple trees. The summers were so short and cold that wood of the Baldwin apple trees did not become fully hardened, though the wood of peach trees seemed to reach approximately its full limit of hardiness. However, in New York bearing peach trees may be killed while dormant at temperatures that would never be injurious to dormant peach trees in a climate like that of Missouri, where the summers are nearly always favorable for the ripening of the wood. The difference may be due to the fact that at higher latitudes the fruit ripens later and thus interferes with the ripening of the wood. Where peaches are grown in such high latitudes that the fruit may not be ripe until nearly freezing weather and the wood does not reach maximum maturity, the wood may be badly killed when the fruit buds are not killed. This would probably never happen at lower latitudes.

The peach tree shows great ability to recover from severe winter injury. Thus, following the winter of 1917–18 at Ithaca, New York, trees that seemed to be killed throughout, recovered and made fairly good growth. The cambium remained alive and a new layer of sapwood formed around the old dead wood. Old trees with large branches and a large trunk are more liable not to recover from such injury than are trees three to five years of age or younger. Fertilizing trees with readily available nitrogen (Oskamp, 1102; Chandler, 970) encourages better recovery; and trees that preceding a freeze were in a vigorous condition recover better than do weaker trees. Trees of full bearing age, which received pruning and other treatment such that during the summer preceding the freeze the twigs grew one to three feet long, recover better than do trees that have had no renewal pruning or other invigorating influence.

Whitten (1167) reported that at Columbia, Missouri, following the cold winter of 1899, severe pruning ("dehorning") in the spring after the freeze caused the trees to recover more rapidly. However, in the same State, such pruning following the winter of 1912 caused many trees to die when adjacent unpruned trees recovered. The same behavior has been observed following cold winters in New York by Eustace (990) and in Massachusetts by Waugh (1159).

The wood of the peach is nearly as resistant as that of the Bartlett pear or the Baldwin apple. Yet, both of these fruits are grown in sections where the peach could not be grown with profit. The difference in distribution is due largely to the fact that the fruit buds of the peach are much less resistant than those of the apple or the pear. Peach fruit buds at their maximum hardiness may be killed by temperatures of about −12° F. to about −22° F. depending upon whether the low temperature comes at a sudden drop from above the freezing point of the buds, or at the end of a long cold period during which the buds have not been thawed. Probably the greater resistance at the end of a rather long cold period is not all due to the slow temperature fall. It may be due in part to wilting of the tissue during the time when the roots, trunk and branches are frozen. Johnston (1042) and others have shown that even during cold weather, loss of moisture from the twigs and buds is appreciable. Further, we cannot be certain that the resistance of the tissue is not increased merely by long exposure to low temperature. It is evident that, but for the influence of bodies of water in preventing such low temperatures from being reached in most winters, there would be little commercial peach growing at higher latitudes than 38° or 39°.

The hardiness of peach buds seems to be slightly less if the summer is a long one and growth is so checked that differentiation begins early and proceeds far before cold weather. However, this is of much less importance with the peach than with the sour cherry or the Japanese plum. It probably never influences appreciably the amount of loss from freezing. Thus, if the freeze comes before there has been warm winter weather to start the buds there will be little difference in the number of buds left on trees whose growth has been checked early in summer and on trees that have grown late. Buds on the base and terminal of long twigs and on small spurs are most resistant and buds on short twigs least resistant (Chandler, 966, 967). This is in agreement with the findings of Roberts (1123), but the differences are less than with the cherry. It is possible that there is a counterbalancing effect. That is, the earlier the growth is checked, the more buds are formed, particularly the more spur buds; and so, with the early checking, there may be when winter begins nearly as many buds in the earlier stages of differentiation as if vigorous growth had continued later.

The greatest reduction in resistance of buds is caused by warm periods in winter, particularly in late winter, which cause them to start into new growth. Warm periods in late autumn or early winter seem to have little influence on the hardiness of buds of normal trees, though the buds of very weak trees might be influenced, particularly if the warm period has been accompanied by rain and the summer has been one so dry that the leaves have fallen very early. Johnston (1042) seemed to find that with peach buds any growth during winter is rather accurately shown by the increase in their moisture content. Thus, during one winter, the moisture content relative to dry weight of Elberta fruit buds was as follows: September 13th, 0.77; September 28th, 0.82; October 12th, 0.80; October 26th, 0.82; November 12th, 0.97; November 23d, 1.00; December 7th, 0.96; December 20th, 0.93; January 3d, 0.88; January 17th, 0.91; January 31st, 0.91; February 14th, 1.05; February 28th, 1.54; March 13th, 1.90; March 24th, 2.25; March 28th, 3.18; April 4th, 4.43. Ice formation in the buds seemed to begin at a little higher temperature when the moisture content was high; though his data concerning this feature are not conclusive. Buds of Greensboro, which are a little more resistant than those of Elberta and Crawford, seemed to have a slightly lower moisture content during late winter and spring than had those of the other two varieties. However, many more varieties would have to be studied before we would be justified in concluding that relative moisture content is a fair measure of the relative hardiness of buds of different varieties.

The rest period of the fruit buds of the peach is generally rather profound until about January even at higher latitudes where chilling weather to break it begins rather early. At latitudes as high as 37° or 38°, if peach twigs are placed in a warm room in early January the buds may grow; but only very slowly. Taken into the warm room in February, they will grow more rapidly, and in March, still more rapidly. In other words, the growth of peach fruit buds may be decreasingly inhibited by the rest period during the time from January 1st to nearly April 1st. Trees that during the previous summer have made a vigorous late growth continue in the rest period later than do trees whose growth has ceased early in summer. Thus, pruning a tree severely in spring or fertilizing it with nitrogen, will generally, by causing it to grow later, cause it to stay in the rest period later in the following winter. In southern Missouri (967) in the season of 1911, such trees were not in full bloom by March 16th; though trees that had not been so invigorated were in a more advanced stage by February 22d. Of course, cold weather intervened. If the February warm period had continued until all trees were in bloom, the vigorous trees probably would not have been more than a week or ten days the later in reaching full bloom. In that section (latitude 37°) in years when the trees reach full bloom by March 15th to 20th, trees that have grown late the previous summer sometimes bloom several days later than others of the same variety; but when the bloom is as late as about April 15, this difference is not to be observed. At Columbia, Missouri (latitude 39°) no difference in time of full bloom due to difference of growth was observed during the period from 1901 to 1913; though warm days in January sometimes caused buds on weak trees to be a little the less hardy. Prolonging the rest period by increasing the vigor is of little practical importance, except in sections where, by early February, there is enough warm weather to start the buds into growth; but at latitudes as low as 37° in the Mississippi Valley, there may be an important reduction in the amount of loss from freezing of buds (and even of blossoms) if by use of nitrogen and by pruning the trees are caused to grow as vigorously as it is possible to have them grow without injuring the quality of fruit borne. Some varieties such as Greensboro, Carman, Mayflower, and Chinese Cling seem to have longer rest periods than others. Thus, at latitudes as low as 36° to 37°, these varieties will generally bloom later than such varieties as Elberta or Crawford Early; though at higher latitudes all bloom about together. Naturally, at lower latitudes such varieties are in less danger than others of having buds or blossoms killed.

The blossoms of the peach are generally more resistant to low temperature than those of the apple. Under some conditions nearly opened blossoms will resist a temperature of 21° to 22° F. When most of the blossoms are open, but some are not fully open, it is doubtful if a temperature of 24° to 25° F. will ever kill a large enough percentage to prevent a full crop from a reasonably heavy bloom. With the peach more uniformly than with most other fruits, there is a rather steady decline in resistance from the unopen bud to the time when the little peach is about one half inch in diameter. At this last stage a very slight freeze may cause the peach to fall, the tissue of the pulp being generally uninjured, but the seed being killed. The peach externally appears uninjured and may make slight increase in size, but it eventually falls. Early varieties may be as resistant as late ones when in bloom, but will soon become less resistant because the fruit develops faster.

Varieties of peaches that are most resistant to one of the above forms of injury are not necessarily most resistant to others. Thus, Elberta is one of the most resistant to killing of the wood but its fruit buds are among the most tender. Since, among the common varieties, there are not large differences in resistance to killing of the wood, and since killing of the wood is less common than killing of the fruit buds, no attempt need be made to classify the common varieties as to such resistance. Among the varieties most resistant to killing of the fruit buds are Greensboro, Rochester, Hills Chile, Crosby, Gold Drop, Triumph, and Snow. Less resistant than these, but more resistant than Elberta, are Carman, Iron Mountain, Lemon Free, Waddell, Hiley, Belle, Champion, and Early Elberta. Few varieties of any importance are less resistant to killing of the buds than Elberta, Early Crawford, Late Crawford, and J. H. Hale.

At higher latitudes where all varieties bloom about together there seems to be little difference in the resistance of flowers; but at lower latitudes varieties such as Greensboro and Carman that tend to bloom the later are naturally in less danger than earlier blooming ones. With the young fruit there is more complication. Thus, at such low latitudes, early varieties such as Sneed or Victor may bloom late, but after pollination the fruit may develop so rapidly that the young fruit soon becomes more tender than that of some earlier blooming varieties.

This discussion should not lead one to expect among peach varieties large differences in resistance to any form of injury. While the differences mentioned exist, they are small, and perhaps more often than otherwise a freeze that kills the trees or destroys the crop of one variety does the same for all others. With peaches, therefore, there does not seem to be nearly as great opportunity for breeding resistant varieties or late blooming varieties as there is with apples. The wood of Greensboro is about as resistant as that of any other variety and the fruit buds are a little more resistant than those of most other varieties. If there could be developed a variety as hardy as Greensboro that bears fruit as desirable for market as that of Elberta, it would cause some reduction in the amount of fruit lost by freezing in some districts; but the difference in hardiness would not be great enough to cause an appreciable extension of the peach-growing area.

The apricot. The apricot fruit and tree show great resistance to summer heat. On the other hand, when grown at Berkeley, California, where the summer temperature is very low (for May, June, and July about 57.3° F., 60.0° F., and 61.0° F.), the fruit acquires more nearly normal quality than is acquired by some varieties of plums or by peaches. The wood of the varieties grown in the northeastern part of the United States (Blenheim, Harris, Alexander, and others) is more resistant to low temperature than that of the peach and is as resistant as that of the Bartlett, Bosc, or Seckel pear, or Baldwin apple. The dormant buds are considerably more resistant to low temperature than are those of the peach, but less resistant than are those of most other deciduous fruits when grown under conditions that favor maximum hardiness. Varieties whose fruit buds are most resistant to low temperature are Russian and Harris. The blossoms and young fruits will withstand about as low temperature as will those of the peach in the same stage of development. At Ithaca, New York, opening blossoms of Russian and Harris apricot have withstood a temperature of 20° F. With the young fruit as with that of the peach, the killing may be in the seed only and there may be appreciable growth of the other tissue before the fruit falls. Like the peach and unlike the apple and pear, however, all fruits with the seed frozen to death seem to fall before ripening.

The most important limiting feature in apricot growing is killing of the blossoms and young fruits. The blooms open so much earlier than those of the peach that only in regions almost free from late spring frosts can crops be expected frequently enough for the tree to be worth the cost of growing. In fact, in the United States, commercial apricot growing is confined almost entirely to California, 96 per cent of the crop of the country being from that State. Blooming in California must be considerably delayed by the rest period. For, in apricot-growing sections of that State, the mean temperature during December, January, and February is as high as the mean temperature for April at Ithaca, New York. Yet in California, the apricot does not bloom until nearly the first of April, while at Ithaca, it blooms during April. Even in California, there is a considerable amount of injury from late spring freezes.

There are a few varieties such as Alexander, Budd, Sharp, and Stella, that in California bloom one week to ten days or two weeks later than the standard varieties such as Blenheim and Royal. It seems, therefore, that by crossing there is some possibility of developing varieties which in that State will bloom enough later than the normal appreciably to reduce the loss from spring freezes. However, in sections where the winters are longer, the different varieties bloom more nearly together and all bloom very early. It does not seem probable, therefore, that the apricot-growing area can be appreciably extended by plant breeding.

The apricot is susceptible to injury by brown rot (*Sclerotinia cinerea*); and its profitable culture is, therefore, limited further to sections with dry enough springs and summers to inhibit the spread of that disease.

The almond. The almond will endure intense summer heat; the wood and fruit buds of some varieties will endure about as low temperature as will the wood and buds of the peach. Taylor (1147) says that blossoms just opening have withstood temperatures as low as 24° F. Hardshell almond blossoms at Ithaca, New York, fully open by April 11, 1921, withstood a temperature of 22° F. from 2 A.M. to 6 A.M. without injury. From experience with the peach and the apricot it is probable that still lower temperatures might be endured in springs such as those of New York. According to Taylor, in all cases known to him blossoms with the petals falling have been killed by a temperature of 30° to 31° F. in California; probably in the dry air and with the very clear skies of that State, radiation would be rapid and the actual temperature of the blossoms lower than that of the air.

The most important feature limiting distribution of the almond is its very early blooming. It blooms considerably earlier even than the apricot. Crops can, therefore, be obtained only in sections rather free from freezes that follow periods of warm weather. Its commercial culture in America is limited almost entirely to California, though in other sections, including the Great Lakes region of North America, hard shell varieties may be grown for home use, crops being obtained in a fair percentage of the years.

The cherry. The sweet cherry (*Prunus avium*) seems able to withstand great summer heat. It does well in the hot valleys of California, though in such regions the trunk is liable to injury unless the tree is so shaped that the trunk is protected from direct sunlight. The fruit, however, ripens more satisfactorily in the very cool summer of the San Francisco Bay region than does that of most other fruiting species. In humid sections, this fruit cannot generally be grown satisfactorily where the summers are very hot because of the injury to the fruit from brown rot (*Sclerotinia cinerea*).

The wood of the sweet cherry is slightly more resistant to freezing than that of the peach, a few varieties such as Lyons and Wood being considerably more resistant. The tree, however, does not have as great ability as the peach tree has to recover from the killing of a large part of the sapwood; and so, following some freezes, a larger percentage of sweet cherry trees than of peach trees are lost; though this is not generally true.

The fruit buds of most sweet cherry varieties are more resistant than those of the peach and very slightly more than those of apricots. As the flower parts grow in the buds in spring they become tender more rapidly than with most other fruits; though, generally, no more rapidly than with some varieties of sour cherries. The flowers are generally a little more tender than those of most other fruits. Further, in the northeastern part of the United States only apricots and some plums bloom as early as the sweet cherry. The sweet cherry tree seems to have a long rest period, most varieties in California blooming as late as the average peach variety or a little later.

The variety that has the most resistant fruit buds, flowers, and wood of any that I have seen is the Lyons. Wood also is more resistant in flower, in fruit bud, and in wood than most other varieties. Ida also is resistant. Black Tartarian, Bing, Lambert, and Napoleon seem among the least resistant. Schmidt is but slightly more resistant in bud and flower, but is appreciably more resistant in wood. Yellow Spanish and Windsor are of medium resistance in bud and flower and among the more resistant in wood.

The wood of the sour cherry (*Prunus Cerasus*) is perhaps a little less resistant than that of the Northern Spy apple. However, Northern Spy trees may suffer from bark injury on the trunk and in the crotches of branches during winters when there is little or no injury to sour cherries.

The fruit buds of the sour cherry at maximum hardiness are more resistant than those of the peach, apricot, or some varieties of plums, though perhaps less resistant than the buds of the average variety of apple. In such condition of maximum hardiness they may survive cold periods that injure the wood badly or kill it all. The killing of such buds is not, therefore, of practical importance. It was shown in Chapter 21 that Roberts found the killing of the flower buds of the sour cherry to be of considerable importance when the seasons or cultural conditions were such that differentiation of flower parts proceeded far before winter began; that buds on spurs and buds at the bases of long vigorous twigs were less advanced in differentiation when winter began than were buds on rather short twigs; and that maintaining the trees at high vigor by good cultivation, the use of nitrogenous fertilizers and rather severe renewal pruning increased the number of fruit buds on spurs and on vigorous twigs.

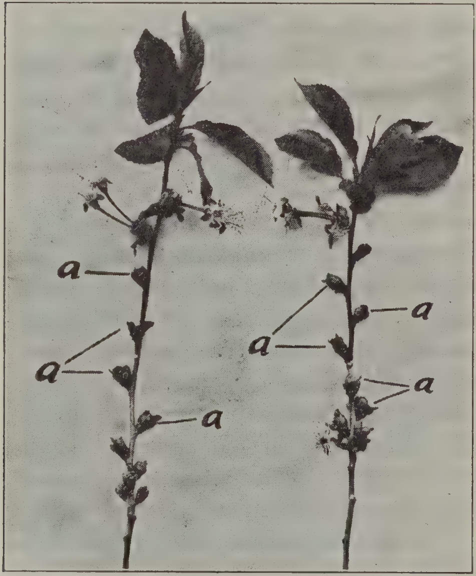

FIGURE 59. Cherry twigs starting into growth in a spring after most of the flower buds have been killed. Fruit buds, in which the flower buds have been killed, open into whorls of bracts, as shown at *a*.

With Early Richmond, if not with some other varieties, only the pistils of the flowers in the buds may be killed and the tree may bear a heavy bloom with almost no live pistils. This phenomenon seems to be more common when the killing occurs after the bud has made some growth in late winter or early spring.

Under some climatic conditions, the flowers of the sour cherry are considerably less resistant than those of the peach and some less than those of the apple. In the earlier stages of opening the flower parts may become tender more rapidly than do those of other fruits. At Ithaca, New York, during the four years beginning with the spring of 1919, killing of the opening buds and flowers by spring freezes was more common with Early Richmond and Montmorency cherries than with any other fruit except some of the sweet cherries. The killing occurred more often when the flower parts were still folded together in the bud than when the flowers were open. The open flowers are less resistant than flowers in the earlier stages of development, but the difference is not great; and freezing weather is more liable to prevail during the earlier stages of opening. With the cherry, as with the peach, the seed is less resistant than other tissue of the fruit and so the fruit may seem uninjured by a freeze and yet fall later, due to the killing of the seed. Where the fruit is large before the freeze, it may become red before falling off, but I have never known fruits with killed seeds to become edible.

The English Morello and related varieties seem to have more resistant fruit buds and the nearly open or fully open flowers are less often killed than with Early Richmond, Montmorency, and related varieties. The wood, also, of the Morello varieties seems to be more resistant to low temperature. Certain Russian varieties such as Vladimir are thought to be a little more hardy even than English Morello.

The trees of the Amarelle varieties, particularly Early Richmond, seem to withstand high summer temperature better than do those of the Morello varieties. Of course, this last difference may all be due to a difference in resistance to diseases that are more serious at lower latitudes. At any rate, in humid climates, the Amarelle varieties can be grown at lower latitudes than can the Morello varieties.

Sour cherries ripen better than do most other fruits in countries where the summer temperature is low. Thus in England the English Morello cherry is sometimes grown against the north side of walls, on the south side of which are peaches. The quality of the fruit is said to be improved by its being grown in such a position.

Among the varieties known as Dukes, which (Hedrick *et al.* 164) are hybrids between the sweet and the sour cherry, there are naturally great variations in hardiness. Some, such as May Duke, are as resistant in wood, bud, or blossom as any of the Amarelle varieties; while others such as Reine Hortense show as small resistance in all ways as the average sweet cherry variety.

The rather great difference among sour cherry varieties as to danger of loss of buds or developing blossoms by freezing, and the large difference in resistance of wood and buds between sweet and sour cherries suggest that by crossing it may be possible to develop varieties with high quality and high vigor of tree that are more resistant to low temperature than are most sweet cherry varieties and some sour cherry varieties.

Plums. There are many species from which commercial varieties of plums have been obtained and among these are shown great variations in climatic response.

Varieties of Japanese plums (*Prunus salicina*) have rather wide climatic adaptation. Except for injury to the fruit from brown rot, in warm humid climates, they can be grown at low latitudes, being resistant both to great summer heat and to winters during which there is little cool weather to break the rest period. On the other hand, the wood of some varieties, at least such as Burbank, Abundance and Chabot, when under good cultivation, is as resistant to low temperature as that of the sour cherry and the Northern Spy apple. With a number of other varieties, the wood does not seem to have great resistance to low temperature.

The resistance of the buds of any variety varies, depending upon the vigor of growth of the trees. Where growth continues late they may withstand temperatures as low as about −30° F.; but if the trees are not well cultivated and fertilized with nitrogen, where necessary, the buds may be killed even in early winter by a temperature not much, if any lower, than that required to kill peach buds. As to the relation of the degree of differentiation of the flower parts at the beginning of winter to resistance, the plum has not been studied in the way that Roberts has studied the sour cherry; but the fact that a weak summer growth may result in fruit buds of low resistance suggests that as with the buds of the cherry, the buds of this fruit are caused to have greatly reduced resistance if differentiation proceeds far before the beginning of winter. On the other hand, if the fruit buds do not go into winter in a very advanced stage, they may be more resistant than the buds of some Domestica varieties such as Reine Claude. In the severe winter of 1917–18, in the Cornell University Orchard, only a small percentage of Burbank plum fruit buds were killed by a temperature of −26° F.; although in adjacent rows a large percentage of the fruit buds of Reine Claude and a number of other *Prunus domestica* varieties were killed. The orchard was well cultivated and the summer of 1917 was short and unfavorable for the development of an advanced stage of differentiation by the beginning of cold weather. With few fruits do the buds so readily start into growth during warm days in winter; and keeping the trees in a rather high state of vigor by means of good soil management and rather severe pruning may be somewhat less effective in regions where there are many warm winter days than in regions where the winters are continuously cold. The rest period is very short even with vigorous trees; and if there should be many warm days in midwinter the buds would be brought to an advanced stage of development before the danger of severe freezing was past, regardless of how much differentiation had been delayed in the previous summer by invigorating cultural treatment.

The blossoms of this fruit open very early. Both opening fruit buds and blossoms are generally more resistant than those of the sour cherry in the same stage of development; but, since the development may come appreciably earlier with these Japanese plums there are years when even with vigorous trees there is more loss than with sour cherries. In other years when the development is more nearly simultaneous there is more loss with the sour cherry. Few trees form as many fruit buds as do Japanese plums; and so if fruit is set from only two to three per cent of the fruit buds formed a large crop may be borne.

The most important species of plums is *Prunus domestica*. The trees of this species are resistant to great summer heat; but, unless the humidity of the air is very low in summer, a rather high temperature may cause brown rot injury to be great in spite of any practicable amount of spraying. The many varieties of this fruit vary considerably in hardiness; but, since not many are grown where the winters are severe, there is little data as to hardiness. The wood of the average variety seems to be slightly less resistant than that of the sour cherry. A considerable amount of bark injury on the southwest side of the trees is often to be observed. Among the less resistant varieties is Bradshaw, while Lombard seems to be above the average in resistance. The fruit buds are sometimes killed in winter in the coldest sections in which the tree can be grown. This was true in New York in the winter of 1917–18; and Goff (1007) reports the killing of the fruit buds of Domestica varieties when the trees were apparently not seriously injured. The loss from this source is not very great, however. The blossoms of *Prunus domestica* are generally slightly less resistant than those of the peach. The wood, fruit buds, and flowers of Damson plums (*Prunus insititia*) seem to be more resistant to low temperature than are those of *Prunus domestica*. In humid climates, Damsons can also be grown at lower latitudes than can *Prunus domestica*. This, however, is only because of their greater resistance to brown rot.

Of the plums from American species the varieties from *Prunus Munsoniana* naturally withstand great heat, being native from Missouri south to Mississippi. They seem to be only a little, if any, less hardy in wood and bud than varieties of *Prunus domestica*. The flowers seem slightly more hardy. The young fruits of Wild Goose, a variety of this species, are more resistant to cold than are the fruits of other varieties of plums or apple and peach fruits, at the same stage of development. The varieties of *Prunus hortulana*, also, seem about as resistant to the climate of low and high latitudes as are varieties of *Prunus Munsoniana*.

The wood and buds of the varieties of *Prunus americana* and *Prunus nigra* are more resistant to low winter temperature than are those of other varieties of plums or varieties of most other fruits. They withstand, uninjured, winters during which the wood of nearly all varieties of apples show some injury and that of such common varieties as Northern Spy is nearly all killed.

The grape. The most important species of grape is *Vitis vinifera*, or the old world grape. There are among the many Vinifera varieties considerable differences in climatic adaptation. The species withstands intense summer heat. When grown for raisins high summer temperature is desirable to cause early maturity so that there will be left a long enough period of hot rainless weather to dry them. The same is true when wines rich in alcohol are wanted, but for light table wines the sugar content may be too high in the hotter valleys. It is desirable, however, that the grapes become fully ripe before there is danger of frost. There is liable to be too much acid in the wine if the grapes used are immature. Bousingault (952) says that in vineyards of Alsace, the best wines are obtained when the summer temperature, and particularly the early autumn temperature, is a little above the average. When the mean summer temperature was as low as 58.4° F., the wine from his vineyard was hardly "drinkable." Excellent wine was obtained when the mean summer temperature was 63.1° F. In the year 1811, which was noted for the fine quality of the wine in Alsace, the mean summer temperature was 67.8° F. and the mean temperature for the months of September and October was 59° F. (about 6° F. above normal). However, in Alsace the seasons are rather short for Vinifera grapes; and in hotter sections the better quality might have been obtained in the cooler summers. Some varieties of table grapes of this species reach their best development in rather hot valleys though not in the hottest. It seems probable that some varieties might be sprightlier in flavor when grown and ripened at lower temperatures, but I know of no studies as to this; and, generally speaking, very cool summers are avoided for Vinifera grapes. Few varieties will ripen satisfactorily in the low summer temperature around San Francisco Bay. Most of the varieties require a rather long growing season as well as a rather high temperature; but Anthony (929) reports a number of varieties ripening at Geneva, New York, latitude about 43°, and one variety, Perle of Csabe, said to be *Vitis vinifera*, ripens at Ottawa, Canada, latitude 45.5°.

This species is not very resistant to low winter temperature. The wood of some varieties when well ripened may withstand temperatures several degrees below zero Fahrenheit; but it cannot generally be depended upon to be so ripened that it will withstand such temperatures. This tenderness of wood is of less importance as limiting distribution than the length of growing season required by the fruit; for the vines can conveniently be covered with several inches of earth and will then withstand the winters of high latitudes. The young shoots in spring are very tender, as with other species of *Vitis*, and may be killed by late spring freezes. The ripening fruit of some Vinifera varieties is more resistant to late autumn frosts than is the fruit of *Vitis Labrusca.* Young shoots of Vinifera varieties may be frozen back in spring; but this behavior will be discussed with that of Labrusca grapes.

Among the different species native to America, *Vitis Labrusca* has furnished much the largest number of important varieties. The species is found wild in eastern North America, primarily in the region east of the Allegheny Mountains. In other words, it is adapted to a humid climate where the summers are not generally very hot. The varieties of the species withstand, reasonably well, the rather high summer temperature of the Mississippi Valley as far south as northern Mississippi, though it seems to be more difficult to keep the vines in a healthy condition there than in the cooler regions along the lakes in New York. This may be largely due to greater injury by diseases in the hot sections.

The fruit of most Labrusca varieties seems to be of better quality when grown where the summers are cool. This may be because the fruit ripens more slowly in cool weather. The ripening of this fruit is hastened by high temperature much more than is that of the apple. Thus, according to Price (1117, 1118) the Catawba grape ripens in northern Mississippi (latitude 34°) about August 3d and the Black Ben Davis apple in the fall or early winter. Yet Ben Davis apples will ripen in sections of New York where the seasons are too short for the ripening of Catawba grapes. Of course, it is barely possible that the high temperature in Mississippi delays the ripening of the apples.

The length of growing season is the most important feature in determining the latitude at which Labrusca grape varieties may be grown. Thus, in central New York, latitude 43°, few varieties can be depended upon to ripen every year except where the influence of large bodies of water prevents the fruit from being killed by light freezes in early autumn; yet, when under protection of such bodies of water, the fruit of varieties of this species will ripen; and the low autumn temperature seems to cause the development of the best quality. At such high latitudes, the most important injury from low temperatures is this killing of the fruit in autumn before it is ripe enough to pick. Few fruits have so little resistance to freezing. The slightest freeze generally kills it, rendering it worthless except for jelly making and some other cooking purposes.

Mature leaves of this species as well as young leaves and the young shoots containing the developing flowers are very tender. When shoots are killed back new shoots will start from the same buds. These will bear some fruit; but less than the first shoots would have borne. If these second shoots are killed a third set may bear some fruit, but much less than the normal amount. We have seen in Chapter 2 that the bud of the grape is a compound one. Nougaret (1097) found, with Vinifera grapes in California, that when the leaves and terminal of a shoot are killed back, the young buds on the uninjured part of these new shoots are the ones that generally grow. If many of these grow, the secondary bud from the same scales from which the original shoot grew may be prevented from growing. Other dormant buds also, such as those at the base of the cane, may be prevented from growing. Shoots from secondary or from basal dormant buds may bear some fruit, but shoots from the young buds of the partly killed shoots seldom or never bear. He, therefore, recommends that, after a frost, young partly killed shoots be broken off (by bending them sidewise). There may then grow from the secondary buds, and from buds that had remained dormant, shoots that will bear some fruit.

With Labrusca grapes, however, if the temperature goes low enough, not only is the shoot killed back to the cane, but the secondary bud at the base of the shoot may also be killed. Angelo (928) found in West Virginia that after a temperature of 23° F., April 21, 1922, when the new shoots were ten inches long with the varieties Catawba, Concord, Moore Early, and Niagara, very few shoots grew from buds that had produced the shoots that were killed by the freeze. Most of the new shoots that grew were from buds that had remained dormant before the freeze and would probably not have grown if the other shoots had not been killed. Of course, it is possible that, if the temperature had not gone so low, shoots might have grown from the same buds that had produced the frozen shoots.

The wood of the Labrusca varieties of grapes does not seem to be more resistant to freezing than that of the more tender apple varieties. According to Gladwin (1003), however, in a region like Chautauqua County, New York, where the vines are protected by the influence of a large body of water, killing generally results only when weather and cultural conditions, during the summer preceding the cold winter, have been unfavorable for the hardening of the wood. There was much wood killing in the Chautauqua section during the winters of 1912–13 and 1915–16; yet in the winter of 1912–13, the temperature did not go below 0° F.; and in 1915–16 the minimum was −13° F. Such temperatures would not kill well-hardened wood. The immature condition of the wood in the fall of 1915 was explained by a low mean temperature during June, July, and August, a large amount of cloudiness and a large rainfall. The leaves of the grape are very susceptible to frost and an early autumn frost sometimes kills off the leaves, thus nearly stopping the hardening of the wood.

The buds or the cane tissue around them may be killed in winter when the remainder of the cane is uninjured. Gladwin thinks from observation in the vineyard that sometimes flower parts in a bud may be killed without injury to the other bud tissue. A barren shoot would then grow from the bud. Barren shoots may result from failure to form flower parts in the bud; and so the presence of barren shoots would not be proof that the flower parts of the bud had been killed in winter. Whether or not killing of the flower parts, without injury to the vegetative part of buds, is reasonably common can be determined only by examination of many buds.

Among the important varieties one of the most tender is Niagara. Not only is the wood more tender than that of other common varieties; but fruits and leaves seem to suffer more damage from light autumn frosts than with some other varieties. Concord, Worden, Moore Early and Catawba are a little more resistant. It would be expected that hybrids between *Vitis vinifera* and *Vitis Labrusca* would be more tender than pure Labrusca varieties. This may be true when large numbers are considered; but Agawam Lindley, Massasoit, Herbert, Barry, Diamond and Delaware seem about as resistant as Concord. However, even Concord may not be pure Labrusca.

Vitis vulpina is the most widely distributed grape species of any importance in North America. It should give varieties resistant to the heat of the Mississippi Valley and perhaps to extreme cold. No variety of high quality has yet been found. With the two most important varieties, Clinton and Bacchus, the vines seem to be more resistant to summer heat than with Labrusca varieties; and the quality of the fruit does not seem to be reduced by hot summers. Yet, even in hot sections, the quality of Labrusca varieties is higher.

The fruit of Clinton and Bacchus requires a rather long summer in which to ripen; and so they cannot be grown at higher latitudes than Concord. In fact, the wood does not seem to be more resistant than that of Concord. Probably there could be developed from *Vitis vulpina* varieties more resistant to high summer temperature and its attendant diseases, and varieties with greater resistance to low winter temperature than those from *Vitis Labrusca.* The difficulty lies in finding varieties whose fruit approaches in quality of the average Labrusca variety.

Vitis æstivalis and *Vitis Linsecomii* have given varieties more resistant to the high summer temperature of regions such as Texas. The varieties seem to be as resistant to low winter temperature as those of *Vitis Labrusca,* but they require a longer season for the fruit to ripen. They are good wine grapes, but are of low quality for dessert. There are other American species, such as *Vitis bicolor,* that have some promise in the development of hardy varieties, but little has been accomplished.

The currant. The European red and black currants seem not to be very resistant to high summer temperature. It is possible that part of this limitation may be due to greater injury from leaf diseases when the growing temperature is high. The fruit of both species ripens well in low summer temperature; and the wood is very resistant to low winter temperature. The currant is distinctly a fruit for high latitudes, high altitudes, or cool coastal sections. Macoun (1066) says that, in the very cold prairie regions of Canada, varieties of the Red Dutch type are considerably more resistant than the large fruiting varieties such as Fay and Cherry. While the wood and buds of the currant are very hardy, the blossoms open in spring about as early as the apple or a little earlier and are in about as much danger of being killed by late spring freezes.

The gooseberry. The European gooseberry (*Ribes Grossularia*) seems to be less resistant to high summer temperature than the currant. This may be due to its great susceptibility to mildew, which is more injurious at high temperatures. This fruit seems to be one of the most resistant to low winter temperature and ripens well in the low summer temperatures of coastal regions such as that around the San Francisco Bay and northwestern Europe.

Varieties of *Ribes hirtellum* and other American species seem generally a little more resistant to high summer temperature than either the European gooseberry or the currant. They are also very resistant to low winter temperature. Macoun (1066) says that in the very cold plains region of Canada, Houghton is found most resistant. Among well-known varieties this one seems to be also the most resistant to high summer temperature. The gooseberry blossoms seem to be in about as much danger from late spring freezes as those of the currant.

The raspberry. The Black Raspberry (*Rubus occidentalis*) seems to withstand intense summer heat better than the red raspberry (*Rubus* *strigosus*), while the latter is the more resistant to long cold winters. Both are better adapted to the climate of the Great Lakes region, the North Atlantic, and the Pacific Coast regions of the United States than to that part of the Mississippi Valley below Iowa with its more severe droughts and more intense summer and winter sunshine. The purple cane varieties, being hybrids between the above two species, seem variable as to resistance. Thus, Cardinal is one of the most resistant of raspberries to the hot summers of central and southern Missouri, while Schaffer does not seem to withstand that climate well.

The winter killing of raspberries is very hard to understand. The winters in which the most harm is done to other fruits may do little harm to raspberries, particularly red raspberries. At Ithaca, New York, following the severe winter of 1917–18, that injured severely nearly all other fruits, red raspberry canes showed little injury; but nearly all canes started growth from even the end buds. In fact these red raspberries showed the least injury that has been shown any year since they were planted in 1914. Black raspberry canes were nearly all killed. They showed the browning that characterizes nearly all wood frozen to death. What injury there was in the red raspberries also showed as a browning of the wood. In other years when the canes were badly killed the wood was not browned. There is some evidence that when canes die without browning, it is not direct freezing to death but a drying to death while water from the soil cannot reach parts of the cane. R. A. Emerson covered canes of raspberries with paraffin and found such canes to survive winters in Nebraska when canes of the same clump not so covered were killed. This suggests a drying to death. He also observed that in years when the snow was so deep that the soil under it was unfrozen, the canes were not killed. However, when he used a mulch thick enough to prevent the soil from freezing he did not prevent the canes from being killed; but examination showed that parts of the canes surrounded by the mulch were frozen. Such a frozen section would prevent the movement of water into the cane. He thinks it possible that, with the thick snow, enough would be melted around the cane for it to be thawed during warm days and thus permitted to obtain enough water to prevent drying to death. If the killing of raspberry canes were a drying to death, then it would not be expected that the worst killing would necessarily result during the coldest winters. The amount of drying out would depend upon the length of time during which the soil was frozen and the rate of water loss from the tissue. The rate of water loss would depend not so much upon the dryness of the air as upon the intensity of sunshine and the amount of fluctuation in temperature. With intense sunlight the temperature of the canes would be above that of the air and the vapor pressure in the cane above that surrounding it. This would cause a movement of water vapor out of the cane. Fluctuations of the air temperature would have the same effect, causing the cane temperature at times to be above that of the air. Winters with many days warm enough to thaw the canes when the soil was frozen should result in the most drying to death.

In the latitude of New York, maturity is important in determining the amount of injury to black raspberries and purple cane varieties. Thus, it is rather easy, by use of much manure, to cause them to grow too late in summer for greatest hardiness. With red raspberries, however, late maturity seems at times to be an advantage. Thus, Card (961a) found at Ithaca, New York, that the young slender canes of Cuthbert that start late in summer often survive the winters better than the larger canes that start earlier in summer. The great resistance of the canes at Ithaca during the winter of 1917–18 has been mentioned. The growing season of 1917 was about one month shorter than normal and throughout was cool and wet so that growth continued late. Very early maturity does not seem desirable with red raspberries.

In extremely cold climates like that of Ottawa, Canada, Herbert is the most resistant well-known variety. Very hardy varieties, such as Sunbeam originated by Professor Hansen of South Dakota and several originated by Professor Macoun of Canada, are of local importance. Red raspberry canes may be protected by covering with a little soil. In fact, it is not generally necessary to have all of the cane covered in order to avoid injury. Among the more resistant varieties of Black Raspberries are Plum Farmer, Honey Sweet, and Cumberland. Because of late blooming and the considerable resistance of the young shoots to low temperature, the raspberry is in less danger from late spring freezes than are most other fruits.

The blackberry. Since the varieties of the cultivated blackberry seem to have been derived from a number of species, no precise climatic requirements can be given. The blackberry plant seems generally to be more resistant to high summer temperature than the red raspberry or even the black raspberry; though the fruit will be dried up worse by hot dry weather during and just preceding picking time than will that of the raspberry. Some varieties are nearly as resistant to cold winters as the Cuthbert raspberry, though the average variety is considerably less resistant to very cold weather than the average red raspberry variety. There will be winters in some sections, however, during which red raspberries will be injured worse than blackberries. While the red raspberry has the greater resistance to extremely low temperature, the blackberry may not be so easily dried to death. Blackberries, much more often than red raspberries, show the wood browning that is characteristic of direct freezing to death.

Of well-known varieties Snyder is most resistant to low temperature. Agawam and Eldorado are a little less resistant; Ancient Briton seems to be very resistant. Mersereau, Blowers, Minnewaski, and Erie are considerably less resistant, and Early Harvest is much less than Snyder. Snyder can be grown well also at lower latitudes than can most common varieties, except Early Harvest and varieties of species native to lower latitudes.

Like the raspberry, the blackberry crop is in less danger from spring frosts than most other fruits because of its late blooming.

The dewberry. Like the blackberry, the cultivated dewberry seems to be derived from a number of species; and so there is great variability as to climatic adaptation. Such varieties as Lucretia and Austin can be grown in as low latitudes as the Snyder and Early Harvest blackberry, or lower. They seem a little less resistant to low winter temperature than the average variety of blackberry; though, since they are so easily covered with a little soil, they can be grown in any climate in which the blackberry can be grown. There are several varieties of the Southern dewberry (*Rubus trivialis*) grown from Virginia south to Florida. In how much higher latitudes they could be grown if desired, with or without covering, has not been determined by experience.

There are a few other small fruits such as the Loganberry, Phenomenal berry and Mammoth blackberry (thought to be derived from *Rubus vitifolius*). The Evergreen Blackberry (*Rubus laciniatus*) and the Himalaya-berry (*Rubus procerus*) do well in the Pacific Coast region and other sections where the temperature does not go far below the freezing point.

The strawberry. This is perhaps the most widely distributed of fruits, being grown in lower and in higher latitudes than are most other deciduous fruits. Since the plants can so easily be covered, coldness of winter is of rather small importance except in sections where it is extremely cold and where there is little snow covering the soil. Some winter killing occurs, but perhaps more heaving out of the soil due to freezing and thawing. The most important injury from low temperature is to the blossoms by late spring frosts. Frosts that do no harm to other fruits injure strawberry blossoms. This is probably because the strawberry is near the surface of the soil where it is coldest rather than because of any strikingly greater tenderness of the strawberry blossom; for when frozen in a chamber with blossoms of other fruits, strawberry blossoms did not seem less resistant than the others. This fruit is different from most others, however, in that the flowers when open, or even when not fully open, are considerably less resistant than the young fruits. Since the strawberry blooms through a rather long season not all of the flowers are in a stage tender enough to be killed by any single freeze. Therefore, in spite of the fact that a frost which does not injure other fruits may kill strawberry blossoms, a fair crop of strawberries may be obtained in years when the entire crop of other fruits is lost.

Different varieties of strawberries show very striking variations in response to the soil-climatic complex of different rather small districts. This is partly a question of the temperature that brings out the best flavor in a given variety. Thus, many varieties are of better quality when ripened in clear sunny weather, while others seem to be better when ripened at a lower temperature. The difference in adaptation of varieties to a section is also due partly to difference in ability of varieties to withstand a low moisture supply, particularly at ripening time.

The persimmon. The American persimmon, *Diospyros virginiana*, is found wild in Florida from latitude 30° or lower to about latitude 38°. In Missouri it may be uninjured by temperatures as low as –25° F. or lower. It has been so little cultivated that its behavior at higher latitudes can be known only from a few experiences. It will survive the climate and ripen fruit in Connecticut, and the Great Lakes region; but there is little or no evidence that fruit of as high quality as some found at lower latitudes can be grown there. In New York the wood does not seem to become as well hardened as in Missouri, though generally there is no winter injury except a killing back of twigs. It is probable that the length of the growing season rather than the minimum winter temperature will determine the height of latitude to which it may be grown. It is probable also that, as with the pecan, varieties developed from strains native to the lower latitudes would be much less resistant than varieties developed from strains native to higher latitudes.

Diospyros Kaki, or the Japanese persimmon, in so far as it has been introduced into America, can be grown dependably only in warm climates; none of the varieties withstanding temperatures below 0° F., most of them being suited only to climates that, except for ocean current influences, would be found at latitudes below 32° or 33°. It is possible that hardier varieties may be introduced from the colder sections of Japan and China. The fruit, of some varieties at least, seems to be able to ripen in a very low summer temperature. Some varieties ripen, though perhaps not entirely satisfactorily, at Berkeley, California, where the mean temperature for the months of June, July, August, and September is about 61° F. And they ripen very well at Niles, where the mean temperature for these months is respectively about 67.2°, 68.9°, 69.0°, and 68.3° F. Condit (76) says that, while the fruit will ripen in such cool coastal climates, the tree is resistant of the high summer temperature of the interior valleys; but not of the very high summer temperature of the Imperial Valley.

The walnut. It is the purpose here to discuss the climatic limitation of only a few of the cultivated nut trees. With all the walnuts the leaves of young shoots in the spring are very tender. The Black Walnut (*Juglans nigra*) and the Butternut (*Juglans cinerea*) are found wild over a very wide area. Strains of them are very resistant to low temperature, and the nuts may ripen in rather short seasons. However, some of the black walnuts found in New York are not as well ripened as those found at lower latitudes, the kernels seeming to be less oily and shriveling to a greater extent as the nuts dry.

The English or Persian Walnut (*Juglans regia*) varies greatly in hardiness. Some varieties will withstand very little freezing weather and some require a long warm growing season so to ripen the wood that it will withstand freezing weather. Other varieties withstand the winter temperatures of the lake sections of New York. There are forms growing in New York, the trees of which are not entirely killed by temperatures as low as −25° F. However, when the temperatures go as low as −10° to −15° F., the twigs are generally killed back considerably; and thus the possible crop is greatly reduced. Close to lake Ontario, in New York, rather good crops of some hardy strains are obtained; but at Avon, New York, not more than thirty miles from the lake, an orchard of about eighteen acres of trees about thirty years old seldom yields more than one good tree might yield in California. This last is due to killing back of the twigs and small branches. Yet, trees from buds taken in this orchard seem to be as hardy as trees of any other strains. Trees bearing reasonably well seem to be more widely distributed in Pennsylvania, in locations where the minimum winter temperature must be as low as at Avon, New York. It is possible that with the longer warmer summers of Pennsylvania, the wood becomes better hardened. This walnut is not grown even in the central or the south central part of the Mississippi Valley as much as in New York or Pennsylvania. This may be due in part to low temperatures reached during single nights in the Mississippi Valley; but is probably due more largely to the late spring freezes following warm periods that start growth in spring, and to early autumn freezes.

In California (Batchelor, 939), unless the soil is well supplied with moisture, a temperature of 100° F. or higher will result in loss of many nuts by "sunburn."

The wood also seems to be injured by the sun. Thus, Batchelor (940) reports sunburn very serious in winter following early autumn frosts that kill off the leaves. Some of this may be freezing to death; and the serious injury to the trunk that he reports must be the result of freezing. When the leaves are killed off before the wood is completely hardened, probably throughout the winter the wood is less resistant, both to freezing and to injury from the sun.

The Japanese walnut (*Juglans Sieboldiana*) is considerably more resistant to low winter temperature than is *Juglans regia.* Some varieties of it are never injured by the winters of Ithaca, New York, where the hardiest known varieties of *Juglans regia* are killed back somewhat every year and very badly in some years. There are some strains of *Juglans Sieboldiana* var. *cordiformis* (the heart-shaped nuts), that will not survive the winters of Ithaca, New York; other strains, however, are as hardy as any of the Japanese walnuts. The trees of this species make much better growth in the cool summers of New York than do the trees of *Juglans regia,* or pecan trees. The young shoots in spring are not so tender as those of *Juglans regia* but are more tender than those of the black walnut or the butternut. It is possible that it cannot be grown well in sections like the Mississippi Valley where late spring freezes are very common. This species, however, deserves study as a promising nut tree for home plantings in all the colder sections of the United States.

The pecan. The pecan (*Carya Pecan*) is found wild from the southern part of the United States and parts of Mexico, north to southern Iowa. The wood of most of the southern strains, however, is very tender, while that of the forms found in Missouri and Indiana will not be injured by temperatures as low as −30° F. The hot summers of sections such as Missouri, to which the northern strains are native, seem to ripen the wood better than do the cooler summers of New York. Young nursery trees grown at Vincennes, Indiana (latitude 38°), and planted in the fall at Ithaca, New York (latitude 42.3°), have not been killed by the coldest winters. Such fall planted trees usually make enough growth the following summer so to ripen the wood that it may survive the following winter; though spring planted trees that start growth later are liable to be killed. If the trees of these hardy strains survive the winter after the first summer they can generally be depended upon to survive the most serious winters, though there is some killing back of twigs at Ithaca; and growth is much slower than in the sunnier, hotter climate of the Mississippi Valley.

As to whether or not pecan nuts of any strain would ripen at as high latitude as central New York, there is little evidence from experience. It is probable that for ripening of the nuts, for hardening of the wood to withstand winter temperatures, and for a satisfactory rate of growth, summer temperature and length of growing season will be more important items than winter temperature in determining the distribution of this nut. Because of its slow growth in cool short summers it does not seem nearly as promising as the Japanese walnut for growing at high latitudes; particularly in sections where the seasons are short and the summers cool. Bixby (946) has given some study to the mean monthly temperature during the summer of sections where pecans are grown, and calls the number of degrees in monthly mean temperature above 50° F. pecan units. Adding such excess degrees for each month gives the number of pecan units for the year. He finds at Evansville, Indiana, about 135 such units, as against 94 for New York and 85 for Hartford, Connecticut. With varieties adapted only to rather low latitudes Stuckey (1143) seemed to find that the nuts were larger at lower than at higher elevations. This might be because of the higher temperature at lower elevations. However, the nature of the soil seemed also to influence the size; and, since the nuts were merely sent in by growers in different sections and little information is given as to details, it is not impossible that all the difference in size was due to influences other than temperature. Greater temperature differences would certainly influence the size of the nuts. Bixby says that when Schley and Stuart pecans fruit in southern Pennsylvania (latitude 40°) the nuts are small and not well filled. These varieties are from strains native to a considerably lower latitude.

The hazelnut. The American hazelnuts (*Corylus americana* and *Corylus rostrata*) are found over such a wide area that, if they were promising for culture, hardy strains could certainly be found. Their habit of growth, however, does not seem very promising as to high production and little has been done toward domesticating them. From several species of European and Asiatic origin have been developed varieties that are very productive. Most commercial varieties, sometimes called filberts, are from *Corylus Avellana*, *Corylus maxima*, or hybrids between the two. These have not been generally successful in America, except recently in Pacific Coast sections where their culture is developing rather rapidly and seems to be promising.

Little is known as to what varieties will withstand winters where the temperature may fall to 0° F. or lower. The wood of many of them at least will resist very low temperature. The most important climatic limitation is the killing of the catkins. These may open during warm periods in early winter or midwinter. They will resist much lower temperature than will the blossoms of most other plants, but may be killed by temperatures well above 0° F. Thus, they survive the mild winters of parts of Oregon, Washington, and California, but are often killed in northeastern and north central United States except in sections where both warm days to start them and extremely low temperatures are prevented by the influence of large bodies of water. In fact, they are often killed even in the Great Lakes region. Certain German varieties, said to be more satisfactory for growth in cold climates, are being tried near Rochester, New York. The Constantinople tree hazel, *Corylus Colurna*, also seems promising for colder sections. It fruits reasonably well in Highland Park at Rochester, New York. Since the wood of most hazels is hardy it seems certain that from comprehensive variety tests and perhaps from some hybridization, strains of this valuable nut could be found that would fruit well in most sections of the United States.

Citrus fruits. The Citrus industry in the United States is a large one and much of it is in sections where winter freezes occur. At such times, there is generally fruit in various stages of development on the trees. This fruit is the most tender part and the leaves next in tenderness. The wood, also, is often killed. Milliken, Tyler, Bonns and Webber (1084) have studied the effect of freezes in California upon Citrus fruits. Some of these authors have also observed the effect of freezes in other Citrus-growing sections. Winberg, Starcher, and Isbell (1172) have studied the effect of freezing in Alabama. All observers agree that under similar conditions of growth the wood of the trifoliate orange and of the kumquat is more resistant than that of common Citrus fruits and that the orange tree is more resistant than that of other Citrus fruits, the grapefruit tree next, followed by the lemon and the lime, the citron being least resistant. Of the oranges, the Mandarin orange, and particularly the Satsuma variety, seems to be the most resistant. Webber and Swingle (1161) made crosses between the trifoliate orange and the sweet orange, applying the term citrange to the progeny and publishing descriptions of several varieties. However, Swingle and Robinson (1146) say that while the citrange when dormant tends to be more resistant to freezing than other oranges, it is easily pushed into a rather succulent tender growth. The kumquat, they say, is not only hardy, but tends to have a rather high degree of winter dormancy. They made crosses between the citrange and kumquat in the hope of obtaining a hardy form that will remain dormant in winter. One variety which they named the Thomasville, withstood a temperature as low as 12° F. Some hybrids between the kumquat and the lime bear fruit of the general character of the lime, but the trees are considerably more hardy.

Citrus trees in an inactive or dormant condition are considerably more resistant to freezing, just as deciduous trees are more resistant in summer after growth ceases or declines than when growth is active. With the exception of kumquats and the trifoliate orange and forms derived from them by crossing, Citrus trees do not seem to have a specific rest period, but respond quickly to favorable moisture and temperature conditions. And so, if there is not a considerable time preceding the severe freezes, during which there is weather cool enough to cause the trees to assume something of a dormant condition, the injury may be much greater than if such cool weather had prevailed. Cultural practices are of great importance in determining the amount of injury. Thus, in California in 1913, trees that had been irrigated about two weeks before the freeze were injured more than trees that had not been irrigated for six weeks, and young trees that continued growth later were considerably more tender than older trees. Trees that started growth under the stimulus of a September pruning were injured more than unpruned trees. With deciduous fruits, the trees would have been in the rest period and such treatments in the fall or early winter would have had little influence on their resistance to freezing.

Winberg, Starcher, and Isbell (1172) say that in December, 1917, a temperature of 17° F., when the preceding weather had been too cool for growth, did no harm to Satsuma orange trees, while 15° F. in February following a warm period caused complete defoliation of nearly all trees. One reason suggested for the greater tenderness of lemons, citrons, and limes is that the trees grow at a lower temperature and are less nearly in a dormant condition. Usually the youngest wood is the most easily killed and the oldest wood least. Sometimes, however, the bark is split from the trunk and some of the wood underneath is killed when branches above are injured but little. Milliken and his associates say that in one place, the trunks of young Washington Navel orange trees remained alive through a temperature reported to have been 5° F. Bark injury seems most likely to occur in the crotches of the branches, as with deciduous trees. These workers seemed to find that when a tree is rather badly killed back from the ends of the branches, it is better to defer pruning until the new growth is well started. If the pruning were done as soon as the first signs of injury were to be observed, wood would be cut out as apparently dead which if left might recover. Thus, the pruning would be more severe and the dwarfing process greater than necessary. Further, some wood would be left that would die and would have to be cut out later, the expense of the pruning thus being increased.

The fruits are killed at higher temperatures than are even the leaves, and generally at considerably higher temperatures than is any wood. The fruit of the pomelo is more resistant than that of the orange, while that of the lemon is several degrees less resistant. Lemon fruits may withstand a temperature of 28° F., but it is not certain that they will always withstand such a temperature. According to Winberg and Starcher the ripening fruit of Satsuma oranges may be damaged by a temperature of 27° F., while that of the kumquat will withstand a temperature of 24° F. These authors recommend that, for Alabama, Satsuma trees be so managed that the fruit will be ripe and can be harvested by early November before there is danger of such freezing weather.

With fruit nearly ripe, when frozen, there is sometimes a spotting of the skin. With all oranges showing such spotting, the pulp also seems to be injured; but the grapefruit may show such skin spotting when the pulp is uninjured. With all there may be injury to the pulp when the skin is uninjured. Thus it is difficult to detect injured fruit; and it is necessary to have some means of avoiding the marketing of such. Thomas, Young, and Smith (1150) found that fruit which is killed loses water and thus comes to have a lower specific gravity. Naturally this difference increases gradually after the fruit has been frozen. Machines have been developed that separate the frozen fruit by means of this difference in specific gravity. The separation is not perfect, because not in every case does the frozen fruit have the lower specific gravity; but it is commercially practicable, at least after the fruit has been held about a month or six weeks after picking, during which time the sound fruit will have increased in specific gravity and the injured fruit will have decreased. Bailey and Wilson (931) placed some frozen lemons in storage the day after a freeze and left some on the tree ten days. Those on the trees were dried out the worst.

Since, in addition to the destruction of a very expensive crop, a freeze may do serious damage to the trees, it is evident that, in a section where such freezes are rather common, orchard heating is more likely to be profitable with Citrus fruits than with deciduous fruits, the wood of which is not injured by temperatures at which heating is practicable. Since fruit may be nearly ready to harvest when the freeze comes, it is more important than with other fruits that heaters with chimneys be used in order to obtain more complete combustion and avoid smoke and soot, which getting on the fruit would damage if for marketing.

Since, if the trunk is uninjured, sprouts from it may form a satisfactory tree, it is desirable in the colder Citrus-growing sections, such as Alabama, to protect the trunk. Winberg *et al.* recommend banking earth around it at the approach of winter.

The avocado. While this promising fruit is of tropical origin, some strains of it will withstand temperatures below freezing. There are strains native to the West Indies, to Guatemala and to Mexico. Of these, the West India race is most tender and the Mexican race most resistant. Webber (1160) reports that a few of the hardiest Mexican varieties such as Knowles and San Sebastian had only the young leaves injured by a temperature of 21° F., though the Guatemalan varieties were badly injured by 24° F., and West Indian varieties were considerably injured by 28° F. Young and vigorously growing trees are injured at higher temperatures. Harris and Popenoe (1021) found the sap concentration in the leaves of the West Indian type lower than that of the leaves of the more resistant Guatemalan and Mexican types. According to Popenoe (1113) the leaves of this fruit, particularly with young trees, are injured in a very dry atmosphere. They are less resistant to such a condition than are the leaves of Citrus fruits. Ryerson (1131) says that the avocado is not very tolerant of high summer temperatures, and even in the more favorable sections of California intense heat waves have caused serious damage.

The mango. This fruit is less resistant to frost than the Mexican or Guatemalan avocadoes, but, according to Popenoe, trees not in vigorous growth may withstand a temperature of 28° or 29° F. It requires a very large amount of heat to ripen the fruit, with some varieties perhaps as much as the date requires. Popenoe (1110) gives a list of a large number of trees that have been planted in Southern California and with none did the fruit ripen well. While the tree may grow well in humid regions, to fruit well, it requires a considerable dry period, a part of which is at blooming time. This is particularly true of the better Indian sorts. Gonzalez (1010) describes a practice in the Philippines known as smudging, by which, in the season of lowest temperature soon after the fruit has been harvested, mango trees are caused to start into a new growth and to bloom earlier than untreated trees. A sort of thatch cover is built over a tree and from a fire the smoke is conducted under the cover. Gonzalez found that by this practice the temperature is appreciably raised; and he thinks it is the additional heat that causes growth to start. We have seen that smoke will break the rest period of deciduous plants. If under the conditions in the Philippines the mango should be thrown partially into a rest, it would seem probable that the smoke might influence growth by breaking the rest period. However, it seems probable that with the mango there is no true rest period and that Gonzalez is correct in attributing the starting of growth and the earlier blooming to the heat supplied.

The date. The date is adapted to commercial culture only in regions of high temperature and low humidity. It shows considerable resistance to low temperature; according to Popenoe (1113) some strains have been known to withstand a temperature of 5° F., and Swingle (1145) says that when dormant the plants will seldom be injured by a temperature of 20° F. On the other hand, Swingle says that no amount of summer heat or dryness of the air will injure the plants, if the roots have access to water. To ripen the fruit well requires long continued high temperature. Swingle gives for a number of hot sections a record of the sum of the daily mean temperature above 64.4° F. during the period between May 1st and October 31st. At Algiers, Algeria, the sum is 1174° F., and no dates ripen; at Orleansville, Algeria, it is 1418° F., and the very earliest sorts ripen; at Cairo, Egypt, it is 2868° F., and at Bagdad 4242° F., and dates ripen regularly. It seems that about 3000° F. above 64.4° F. are necessary to ripen dates. That would be equal to a mean daily temperature of 89.4 for 120 days. At Tucson, Arizona, only very early sorts ripen.

The fig. The fig is a deciduous fruit tree, but subtropical in climatic requirements; though some varieties are grown at higher latitudes than with most other subtropical fruits. In resistance to low temperatures, it is about equal to the Japanese persimmon. Some varieties may be grown along the Atlantic Coast at latitudes as high as that of Norfolk, Virginia. Away from the coast at such latitudes it must have some winter protection. Rather mild early winter freezes will kill the twigs and sometimes the larger branches and the trunks of trees during their first two or three years in the orchard. It is coming to be the custom in some parts of California, early in the fall, to set up cornstalks or other such material around the trunk and among the branches of young fig trees. Older trees are seldom frozen back in fig-growing sections of California; but there is occasionally winter sun scald on the trunks or large branches. Such injury seems to be reduced by keeping the lower parts of the trees whitewashed, in sections where the injury is common enough to justify the expense. With caprifigs, the young figs that are borne during the winter may be killed; and the *Blastophaga* wasps in them will perish. The supply of wasps for carrying pollen in the next year may thus be reduced (Condit 77). For most varieties, sections where the summers are cool or short are to be avoided because the fruit does not ripen well there. However, some varieties such as Brunswick will ripen well in sections where the trees or bushes must have protection in winter, at latitudes as high as Washington, D.C. And late in autumn, ripe fruits can generally be obtained from the Brunswick variety at

Berkeley, California, where the mean temperature of the warmest months is about 61° F.

The olive. The olive is perhaps about as resistant to low temperature as the hardier strains of figs, or slightly less resistant. Crider (980) says that at Tucson, Arizona, bearing trees have withstood a temperature of 6° F., with injury only to the foliage and the youngest wood, though young trees were frozen to the ground. The fruit may be injured by a temperature of 24° to 26° F. In California, where the olives are preserved ripe, the fruit must be left on the trees so late that some of it may be injured, by freezing, and rendered undesirable for preserving. The blossoms, while surviving light frosts, are killed by rather heavy ones. The olive requires for successful culture a dry climate; rains, at blooming and ripening time, being particularly harmful. Rather high summer temperature and long summers are required to ripen the fruit or even to bring it to the proper development for preserving green.

The loquat. According to Condit (974), the loquat tree in Raleigh, North Carolina, withstands temperatures of 8° to 10° F.; and in California the flowers are seldom killed by a temperature of 27° F. The flowers appear in California from October to January; the young fruits setting in winter. Condit says that, while the blossoms are seldom killed in California, the young fruits are often killed. The seed is the most tender tissue; if killed before the fruit is more than half grown, the fruit does not seem generally to fall, but continues development; seedless fruits being formed. The fruit is most susceptible to injury at about the stage when it is beginning to color; and early varieties that reach this stage before danger of freezing weather is past are most liable to be killed. The fruit may ripen in the very cool climate of the San Francisco Bay region, but does not develop as high quality as when ripened at higher temperatures. The tree is very tolerant of high summer temperature, but the fruit may be sunburned if very high temperatures accompanied by hot winds prevail before it is harvested. With most of the varieties, however, if grown in hot valleys, the fruit, it seems, will be harvested before there is danger of such hot winds.

Other tropical or subtropical fruits. The guava (*Psidium Guajava*) can be grown without danger of injury to the plants only in the warmest sections of California; being as restricted as the avocado. However, the strawberry guava (*Psidium Cattleianum*) is as hardy as the orange, or more hardy (Popenoe, 1113).

The Feijoa (*Feijoa Sellowiana*), closely related to the guava, is hardier than most other subtropical fruits. According to Popenoe (1113), it has withstood temperatures of 15° F.; and Popenoe (1111) says it can be grown as a shrub in some parts of England, though it does not fruit well. The fruit ripens in California in sections where the mean temperature of the warmest months is about 65° F.

The Cherimoya (*Anona Cherimola*), said to be the best of the fruits of the genus Anona, is, unlike the other species, subtropical in requirements. At latitudes as low as Central Mexico, it fruits best at elevations of about 7000 feet. The fruit is said to be of better quality when grown in a section of moderate temperatures. When grown in a hot climate, it is said not to be superior to the fruit of *Anona squamosa*. According to Popenoe (1112), it may, in colder sections of Mexico, lose its leaves in the winter months, behaving much like a deciduous tree. The fruit ripens well in Southern California, though few of the trees (mostly seedlings) grown there are very fruitful; the failure to fruit is thought to be due to lack of pollination.

Hodgson (1031) says that the pomegranate is more hardy than Citrus fruits, but will not safely withstand a temperature lower than 8° to 15° F. However, it will withstand the most intense summer heat, and, to ripen its fruits properly, requires a long hot summer. Near the coast in California or in other cool regions it does not develop high color and remains too acid in flavor.

Thomas (1149) quotes Fairchild as saying that the jujube (*Zizyphus Jujuba*) has been known to withstand temperature as low as –22° F. But in sections with cool summers the fruit drops or is of low quality. It blooms late and is in little danger from late spring frosts.

CHAPTER 25

THE STRUCTURE, COLOR, AND QUALITY OF FRUIT, AND SOME CHANGES IN COMPOSITION DURING THE RIPENING AND LATER

In previous chapters there have been discussed the influence of cultural treatments and of climate on the nature, size, color or quality of fruits. Knowledge in detail of the nature of the fruit as to structure, color, and the changes that occur in ripening should be helpful toward an understanding of the effect of cultural practices upon these characters, and toward a solution of problems in fruit harvesting, storage, and transportation.

The structure of the fruit. Information furnished by the studies of Kraus (1273, 1275), McAlpin (1289, 1290), Brooks (1201), and others concerning the structure of fruits should be of much value in explaining injuries that develop in handling fruit and might suggest a relation between internal structure of a variety or kind of fruit and its desirability for different uses. It is not the purpose to discuss many of the details of that structure. A feature that seems to be of much importance in the development, perfection, and keeping quality of the fruit is the elaborate vascular system. McAlpin and also Kraus, by dissolving out a large part of the other tissue, have shown strikingly how extensive it is with the pome fruits. Kraus says that, particularly near the epidermis, the tissue is densely filled with fibers which divide, subdivide, and anastomose profusely; but in the pith, a considerable area surrounding the core, there is no vascular system except for the passage through of certain bundles.

Studies made by Kraus (1275) concerning the internal structure of the fruit of different apple varieties suggest that after much study it may be possible to identify varieties with more certainty from their internal structure than from external characteristics. Milam and Gardner (1291), working in Kraus's laboratory, seemed to find a study of the internal structure of some value as indicating the best culinary uses to be made of varieties. McAlpine (1289) suggested a relation between the perfection of the vascular network of the apple and the development of such injuries to the fruit as "bitter pit." Cultural methods that modify the nature of the fruit, as to size and in other ways, should modify the completeness of the vascular system throughout the tissue and thus influence its susceptibility to certain injuries that may be observed during storage or before harvesting.

Cummings and Lombard (1227) seemed to find a relation between the cellular structure of apple flesh and keeping in storage. Thus, Roxbury, which is known to keep long in storage, contains smaller cells with thicker walls than most varieties. Ben Davis approaches Roxbury, while with Baldwin the cells are larger with thinner walls. Of course, it would require the study of many varieties to determine whether or not such cell structure as that of Roxbury is generally found with varieties that keep exceptionally well in storage.

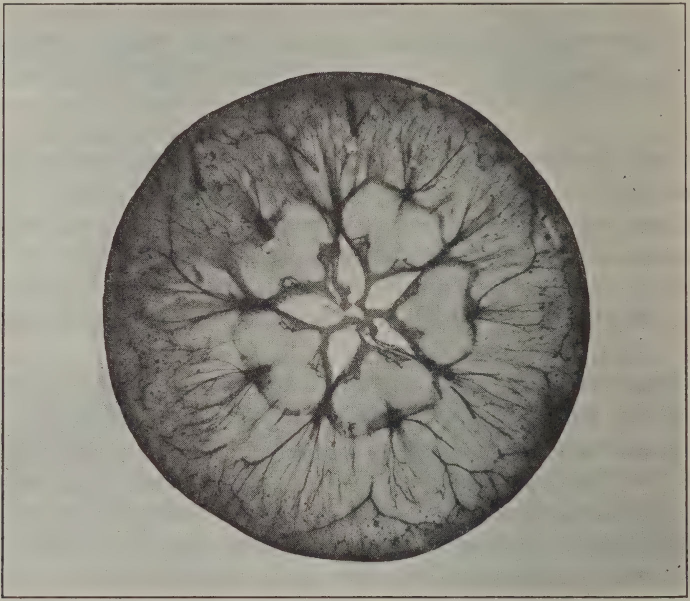

FIGURE 60. Cross-section of an apple rendered translucent by treatment in cedar oil. Part of the vascular system shows. Note the thick mass of bundles near the periphery, and the absence of vascular tissue in the part surrounded by the "core lines." (After Kraus.)

The nature of the epidermis of the fruit is of importance as influencing its resistance to injury in handling. This tissue, according to Strasburger and Hillhouse (1349), is composed of comparatively small polygonal cells with which grouping as a result of development can still be recognized. The walls of the cells are rather strongly thickened, their cell sap either colorless or red. The small prominences of the apple which are readily visible with the lens are occupied each in its center by a stoma. The tissue under such a stoma is often dead; or the epidermis is ruptured and the wound closed with cork. Below the epidermis lie several layers of tangentially elongated cells with rather thick walls; the cells of the inward layers being the larger and thinner walled and containing chlorophyll. Cummings and Lombard seem to find a relation between the structure of the epidermis and the keeping quality of apples. The epidermis of the fruit is modified to fulfill its needs, according to these authors, by cutinizing of the outer wall. This cutinizing consists of the deposition of a waxy substance intermixed with nearly pure cutin and some unaltered cellulose, which is infiltrated with oils and waxes. (Sando, 1338, has determined a number of the constituents of this waxy covering). Suberization of the cell walls is another means of protection. Cummings and Lombard found Roxbury (one of the longest keepers) to contain a very thick cuticle with much suberization. Ben Davis showed this condition to a slightly less extent, Rhode Island Greening considerably less, and Oldenburg still less. Of course, many varieties must be studied before it can be known whether or not there is a high degree of correlation between epidermal structure and keeping quality. Certainly other features, associated with the metabolism of the fruit, would seem to be of greater importance than epidermal structure.

Elongations of epidermal cells of some fruits, such as peaches and some raspberries, form the plant hairs found on the surface. No effect of these on resistance in storage or handling has been shown. With the peach this pubescent surface holds spray material and thus increases the degree of success in spraying.

Color in fruit. Color in fruit is of marked importance in increasing its attractiveness and, therefore, its value. A review of the literature concerning the chemical nature of such color pigments, though requiring much space, would contribute little if anything toward the solution of any problem as to orchard practices that would result in the development of the most attractive color.

Carotin, a hydrocarbon with the formula $C_{40}H_{56}$, is widely distributed in plant tissue. It is associated with chlorophyll in the chloroplasts. It occurs also, according to Hass and Hill (1257), in different forms, amorphous or crystalline, in various parts of many plants. In the plant, it usually gives the color of orange or orange-yellow. A closely related hydrocarbon, xanthophyll, has the formula $C_{40}H_{56}O_2$. One or the other of these compounds may be generally responsible for the yellow colors that develop in ripening fruit. Light directly on the fruit does not seem to be required for the development or deposition of either. As the fruit ripens in storage, the yellow color becomes more prominent, perhaps partly because of the disappearance of the chlorophyll that has obscured it, and partly because of an increase in the amount of one or both of these pigments. By some these pigments are thought to be formed in special organs, while by others they are thought to be decomposition products of chlorophyll (Haas and Hill, 1257).

Duggar (1233) has reported an interesting study concerning the pigment giving the red color to tomatoes and peppers which he calls lycopersicin. It is found generally in the tissue as needle-shaped crystals, but also as elongated bars and in other forms. When green tomato fruit is picked and ripened at a temperature of 30° C., or higher, the deposition of the red pigment is suppressed, partially or completely; a yellow-orange, or orange-red color resulting. This inhibition of pigment formation at high temperature was observed also with fruits on the vine. If the temperature of fruit that had been held at a temperature of 30° C. or higher was brought to 18° to 25° C., rapid formation of the pigment occurred. In other words, the ability of the fruit tissue to form the pigment was not destroyed permanently by exposure to temperatures of 30° to 37° C. With pepper fruits, the red color would develop at any temperature below the point of injury. When oxygen was excluded from tomato fruits the red color would not develop appreciably. However, when over fruit that was held at 37° C. a stream of pure oxygen was passed during twelve hours of each of four days, the fruit did not develop the red color. In other words, the inhibiting effect of high temperature on color development was not obviated by increasing the oxygen supply to the surface of the fruit. It may be that at the high temperature there was very little oxygen among the gases of the tissue regardless of the external supply; and it must be the oxygen within the tissue that is used. Carrick, in some unpublished work, found that, with tomatoes held in storage three or four days at 32° F., the development of this red color might be delayed two weeks or more.

Anthocyanin is a collective name for a number of pigments that are responsible for red, blue, or purple colors in some tissues. The pigments may be dissolved in the cell sap or in the form of crystals. They are glucosides which upon hydrolysis yield one or more molecules of a carbohydrate besides an anthocyanidin. Anderson (1190) studied the pigments of the purple grapes Norton and Concord. He found this to consist principally of a monoglucoside (though there seemed to be also some diglucoside that was not separated out) the chloride of which corresponded to the formula $C_{23}H_{25}O_{12}Cl$. On hydrolysis with boiling hydrochloric acid the anthocyanin chloride yielded one molecule of glucose and one molecule of the sugar free anthocyanidin chloride $C_{17}H_{15}O_7Cl$. The pigment of these grapes (*Vitis æstivalis* and *Vitis Labrusca* respectively) in nearly all of its reactions was found to resemble the pigment of dark blue grapes of the species *Vitis vinifera* studied by Willstätter and Zollinger (1381).

Red color development in some fruits, such as the apple, the pear, and the peach, is determined by the presence or absence of sunlight on the fruit. In this case, there is no increase in the amount of red color after the fruit goes into storage; though the color contrast may become greater due to the disappearance of the chlorophyll. With some other fruits, such as the strawberry, cherry, blackberry, and grape, anthocyanin color will develop in absence of light. In most of these fruits, the color extends through the flesh, though in the skin it may be of a different shade or more intense. In some fruits, such as certain Japanese plums and the amarelle group of cherries, though the flesh may be intensely colored the juice is colorless, while with others such as the morello group the juice is colored.

Overholser (1302) has made a study of the effect of excluding light on the development of color in fruits. He used black cloth bags that seemed completely to exclude the light. With the apple when three thicknesses were used the color of the fruit was the same as when but one thickness was used. This suggests that light rays that influence the color of apples were satisfactorily excluded by a single thickness of the cloth.

Generally with apples, pears, peaches, nectarines, and apricots, no color, except yellow or green, developed in the absence of light; and the yellow was more pale than on specimens exposed to light. However, with one variety of apple, Williams, in absence of light there were splashes and stripes of red with a yellow ground color. The fruits of Moore Early and Concord (*Vitis Labrusca*) and Bacchus (*Vitis vulpina*) grapes, McAlpine strawberries, and May Duke and English Morello cherries colored and ripened normally in the absence of light. Those of Diploma currant (*Ribes vulgare*) and Houghton gooseberry (*Ribes hirtellum*) developed about fifty per cent or less of normal color; while those of Mersereau blackberry, Vladimir (*Prunus Cerasus*), and Windsor (*Prunus avium*) cherries in the absence of light developed normal color eventually; but the fruit was delayed in maturing. With Early Richmond cherry (*Prunus Cerasus*) and plums of the *Prunus Munsoniana* and *Prunus americana* species, a very small amount of red developed in the absence of light; and with Burbank plums (*Prunus salicina*) only lemon yellow developed. Observation in the orchard suggests that with some of these fruits, such as the Burbank plum and the Early Richmond cherry, partial shading caused by a rather dense foliage is not as injurious to color formation as with the peach or the apple. Except with the apple three thicknesses of the black cloth were used; and it may be that with some of the fruits the exclusion of oxygen was more detrimental to color development than was exclusion of light. In fact, Overholser, in some unpublished work, seemed to find that such was the case with the Japanese plums.

Obaton (1300) has studied the reddening of ripening cherries. He does not say what variety was used, but it was probably a variety of *Prunus avium.* Generally, in nature, the fruits exposed to sunlight redden the more rapidly; but when he ripened fruits in each of two chambers in which the temperature was kept the same, but in one of which a glass front permitted the entrance of sunlight, the fruits reddened with equal rapidity. He concludes that the more rapid reddening of fruits normally exposed to light is because, during part of each day, they reach a higher temperature than that of shaded fruits. It seems probable that the differences observed by Obaton were differences in the rate of ripening rather than differences in the degree of redness reached by fruit of equal ripeness, sunlight on the fruit not being necessary for the development of red color.

Evidence has been suggested that the formation of anthocyanin in plants is controlled by a specific oxidase. It is certainly dependent on the presence of oxygen surrounding the tissues.

There seems to be little that can be done to influence the color of fruits in the orchard. With apples, peaches, and nectarines, which for the development of high color require strong light, thinning the fruit and pruning to open out the tree will improve the color by increasing the amount of light to reach the fruit. Thinning the fruit may influence slightly the amount of red color developed by reducing the amount of tissue into which the available sugar and other carbohydrate supply may go, a high sugar content often being associated with high color. Cultural and fertilizer practices seem to influence the amount of red color developed only as they influence maturity and the amount of shade in the tree. Thus, late fall and winter apples will be more highly colored in a sod orchard because they are riper when picked. Summer apples, peaches, apricots, nectarines, and Japanese plums will become ripe and therefore well colored earlier in a sod orchard. As a matter of fact, all these fruits will reach a higher ultimate color in a sod orchard, since, on account of the reduced foliage, more sunlight reaches the fruit. Of course, since it is from compounds related to the sugars that anthocyanins seem to be derived, it is possible that more red color may develop in the sod orchard due to the early checking of growth and the consequent accumulation of such substances. Ringing the tree might, by causing the accumulation of such substances in the top, increase the amount of red color in the fruit; though not necessarily the brightness of color. If influencing the carbohydrate concentration in the top of the tree, by ringing, growing in sod, or other treatment, should appreciably increase the amount of red color in the fruit, it seems probable that fruits which ripen early before there is large accumulation of carbohydrates might have their color influenced more by such treatments than would fruits which ripen after the accumulation of an abundance of carbohydrates. On the other hand, it seems probable that with late-ripening fruit such early checking of the growth and consequent reduction in leaf surface might in unusual cases result in a smaller supply of such compounds at fruit-ripening time and a reduction in the density of the red color. However, with such fruits as the apple, which for coloring require sunlight directly on the fruit, the increased exposure to light would generally much more than offset any such influence on the amount of the substances from which the anthocyanins are developed. In fact, if treatments that augment the accumulation of carbohydrates increase color of fruit, except by hastening its maturity or by increasing the amount of light to reach it, experience suggests that such influence must be rather small.

Fertilizers used in the orchard seem to affect color of the fruit only through their influence on vigor of growth of the tree, time of ripening of the fruit, and density of foliage. Of the elements commonly used, the only measurable effect follows the use of nitrogen, which, by delaying maturity, delays development of color and, by increasing the vigor of growth and thus reducing the amount of sunlight that reaches the fruit, reduces the intensity of color at complete maturity. It may also, in some cases, reduce the available supply of the substances from which the anthocyanins are formed. Most varieties of apples, unless they are fully ripe and mellow when picked, will, if exposed to sunlight after picking, continue to develop red color. This is seldom if ever a practical method of increasing color; for the keeping quality of the fruit is thus impaired.

Stings of insects and other injuries to the skin often cause the development of red color. With peaches the amount of red color is increased by spraying the young fruit with lead arsenate. Sometimes this is of considerable practical value, such highly colored fruit bringing exceptional prices. The increased color apparently results from injury to the skin; and, if the concentration of the lead arsenate is too high, the injury may be so great that an unattractive purplish red results, or even a pitting of the surface. The concentrations commonly used in spraying practice, however, generally give an improved color without objectionable injury. No method has been observed by which the color of other fruit can be appreciably influenced by material sprayed onto it. Perhaps the pubescence of the peach renders possible such a stimulation to color development without undesirable injury to the skin. Injury to the skin that would result in such deep red color might reduce the value of peach and apricot fruits for canning. The skin might adhere too tenaciously and there might be undesirable red streaks in the flesh. However, I know of no careful observations as to such influence.

It should be emphasized that it is not the density of color that gives attractiveness to the fruit, but brightness of color. We have seen that with apples abundance of irrigation in some sections gives increased brightness to the skin. Fruits of the apple and especially of the peach which, near the ripening time, have an inadequate water supply, whether it be due to inadequate soil water or to being far out on sharply bent, unpruned branches, tend to have more abundant color, but a dull and less attractive color, than that of fruits growing in limited light and having an adequate water supply. With the inadequate water supply or excessively intense sunlight there seems to be a development of a steely gray scarf skin that reduces the amount of contrast between the red and the bright yellow. It may be that the more dull color of fruits grown where the summer temperature is too high for the variety (Shaw, 1341) is due to the development of such confusing colors rather than to a reduction in the amount of red.

With cherry varieties such as Early Richmond, Montmorency, and Windsor, and with other fruits whose ripening is delayed by lack of sunlight, cultural practices, including the use of nitrogen, may influence the time of ripening largely by influencing the amount of foliage. Thus, deep in a dense headed tree of such cherry varieties the fruit ripens later than at the periphery. However, the color when ripe is apparently about as intense as that of exposed fruits. The time of ripening is also influenced directly through the influence of the nitrogen on the vigor of the tree. In other words, if much nitrogen is used the fruit will ripen later because of the vigorous condition of the tree and also because of the shade of the dense foliage; and, conversely, growing the tree in sod may hasten ripening both by hastening maturity of the tree and by reducing the density of the foliage. Partial shade, as from a foliage of medium density, does not seem to influence the ripening or coloring of such fruits.

Factors and conditions that influence quality of fruits

It is the purpose here to discuss only the factors that affect quality in fruit, when at the optimum state of ripeness; leaving a consideration of the ripening process for a later discussion. Shaw (1341) stresses the importance of the percentage of insoluble solids, and the amounts of sugar relative to that of acids in determining palatability of apples. A low percentage of insoluble solids he considers to be associated with thin cell walls or tender flesh. The desirable ratio of total sugars to acid will be different for different persons, but in most cases a high sugar content should for best flavor be associated with a high acid content and a high acid content with high sugar. He says that when the sugars are in proportion of two thirds reducing sugar to one third sucrose with the sugar-acid ratio indicated in Table 68, apples have the flavor indicated.

TABLE 68. SHOWING THE SUGAR-ACID RATIO OF APPLES OF DIFFERENT DEGREES OF ACIDITY

FLAVOR	TOTAL SUGARS TO ACID AS MALIC
Sweet	1 : .010 to .025
Mild sub-acid	1 : .025 to .035
Sub-acid	1 : .035 to .045
Acid	1 : .045 to .060
Very acid	1 : .060 to .085

Shaw analyzed, for insoluble solids, sugar, and acid, a considerable number of varieties of apples. In Table 69 are given his results and the quality of the varieties used as indicated by Beach *et al.* (43). In that publication the term "good to very good" is applied to a variety such as Baldwin, that is of medium quality, while the term "good" is applied to a variety such as Ben Davis, having quality below medium, and the term "very good" to a variety having quality above medium.

With most of the varieties not enough analyses were made to be more than suggestive. Wealthy, McIntosh, Jonathan, and Northern Spy have rather low percentages of insoluble solids. They are varieties with a pleasant texture, though not more pleasant than that of Fameuse. Generally the varieties of lowest quality, such as Ben Davis, Smith Cider, and Rome Beauty are high in percentage of insoluble solids. On the other hand, Grimes Golden and Newtown are rather high in insoluble solids. It has been suggested that high insoluble solids content is associated with rather thick cell walls. It is probable that the chemical nature of the cell wall as well as its thickness may be important in determining quality. Thus, some varieties of apples are good as long as

TABLE 69. PERCENTAGE OF INSOLUBLE SOLIDS, SUGAR, AND ACID FOUND IN CERTAIN APPLE VARIETIES AND THE QUALITY OF THE VARIETY

(Green weight)

VARIETY	NUMBER OF ANALYSES	INSOLUBLE SOLIDS	REDUCING SUGARS	SUCROSE	TOTAL SUGARS	ACID AS MALIC	RATIO TOTAL SUGARS TO ACID	
Wealthy	3	2.11	7.40	1.71	9.11	.50	1 : .055	Good to very good
Maiden Blush	3	2.66	4.80	3.14	7.94	.63	1 : .079	Good
Fameuse	5	2.64	7.72	1.38	9.10	.39	1 : .043	Very good
McIntosh	6	2.32	7.21	1.91	9.12	.38	1 : .042	Very good to best
Jonathan	10	2.38	8.28	1.65	9.93	.42	1 : .042	Very good to best
Grimes Golden	11	2.70	8.77	4.30	13.00	.45	1 : .035	Very good to best
Tompkins King	2	2.45	8.43	2.39	10.82	.38	1 : .035	Very good to best
Rhode Island Greening	4	2.89	6.10	3.27	9.37	.59	1 : .063	Very good
Northern Spy	10	2.39	8.00	2.22	10.22	.44	1 : .043	Very good to best
Baldwin	9	2.71	5.74	3.91	9.65	.55	1 : .057	Good to very good
Esopus Spitzenburg	2	2.67	7.00	3.66	10.66	.56	1 : .053	Very good to best
Green Newtown	2	2.75	7.59	3.07	10.66	.47	1 : .044	Best
Winesap	7	2 71	10.02	2.20	12.22	.47	1 : .038	Good to very good
Stayman	3	2.78	8.11	3.44	11.55	.52	1 : .045	Good to very good
Rome Beauty	3	2.89	6.77	3.16	9.93	.41	1 : .041	Good
Smith Cider	2	3.30	7.54	2.37	9.91	.51	1 : .051	Good
Roxbury Russet	4	2.82	7.43	4.85	12.28	.59	1 : .048	Good to very good
York Imperial	7	2.69	7.96	3.04	11.00	.39	1 : .035	Good to very good
Ben Davis	11	3.07	6.91	2.95	9.86	.44	1 : .045	Good

they are sound, while others become dull in flavor. Bigelow, Gore, and Howard (1196) seemed to find that such dullness in flavor results from a softening of the middle lamella so that the cells are easily separated from each other without being ruptured, the flavors within the cells not being tasted. Such a difference in behavior among varieties may be due to a difference in the chemical nature of the middle lamella more than to the thickness of the cell wall.

The table does not suggest that the sugar-acid ration is very important in determining quality. Green Newtown, the variety highest, and Ben Davis, the lowest in quality, have approximately the same sugar-acid ratio; while Rome Beauty, with its low quality, has nearly the same ratio as Fameuse, McIntosh, Jonathan, and Northern Spy, all varieties of very high quality. Smith Cider, also of low quality, has approximately the same ratio as Esopus, one of the best. It is possible that if more varieties were used and more specimens were analyzed from each variety, some correlation would be found between the sugar-acid ratio and quality. It is certain that the amount of sugar and of acid in the fruit is of importance in determining quality. But that the ratio they bear to each other is so important that its influence can be detected among the many other features is not so certain.

Much of the pleasure of eating an apple is due to the odor. Power and Chestnut (1318) distilled in steam the parings of Ben Davis and Springdale apples and of certain crabapples and studied the resulting liquid, which possessed, in a high degree, the pleasant odor of ripe apples. They found the odorous constituents of these apples to be the amyl esters of formic, acetic, caproic and (to a less extent) caprylic acid, together with a considerable amount of acetaldehyde. Acetaldehyde was found also in the natural emanation from Nero apples. It seems certain, therefore, that this substance is a product of the vital activities of the apple. Very small quantities of methyl and ethyl alcohols also were found. Amyl valerate is known in chemical literature as "apple oil," yet these workers could find none of it in the apples studied. These odorous constituents are not easily studied; but it is desirable that we know not only what constituents are generally found, but which of them are responsible for the characteristic odor of particular varieties and how each is influenced by temperature and other conditions during ripening.

There are other substances that influence the flavor of fruits, such as that (probably tannin) which gives the astringent character to such varieties as Maiden Blush, Winter Banana, and, to a less extent, Northern Spy. Flavor is probably influenced by a considerable number of other substances and by the nature of the tissue itself, as influencing the ease with which the juice of the fruit is released. It seems certain, too, that this ease with which the juice is released is not determined by the insoluble solids alone, or by the nature of the middle lamella; the size of the cells also must be of considerable importance.

Excellence for cooking in apples is not necessarily associated with high quality for eating fresh. Generally, a higher proportion of acid is desirable for cooking apples. The nature of the cellular structure desirable for cooking will depend on the use to be made. For sauce the cells should part from each other readily; while for baking this is not desirable. Milam and Gardner (1291) find that apples with a large pith area are less desirable for sauce, since the small elongated pith cells, with no fibrous tissue, adhere firmly to each other. They find that desirability for sauce is correlated with largeness of cells; while the flavor and texture of jelly yielded by a variety is not influenced by the cellular structure, but is determined by chemical composition.

Since there has been little study of the factors that influence quality in other fruits than the apple they will not be discussed in detail. Power and Chestnut (1319) studied the odorous constituents of peaches and found them to consist chiefly of the linalyl esters of formic, acetic, valeric, and caprylic acids and a considerable proportion of acetaldehyde, with a very small quantity of an aldehyde of a higher molecular weight. They extracted an essential oil which contained the esters named and acetaldehyde and possessed an exceedingly pleasant peach-like odor. It was apparently a paraffin hydrocarbon and was exceedingly unstable when exposed occasionally to the air. No trace of hydrocyanic acid or benzaldehyde could be detected in the distillate of the pulp. They conclude that the glucoside amygdalin, which is capable of yielding these substances, is to be found only in the kernel. These workers (1320) found that one of the substances that give character to grape juice and, perhaps, the characteristic odor to grapes is methyl anthranilate. It was suspected that in commerce this substance is added to grape juice to improve its flavor, but they seemed to find that it is a natural and constant constituent of grape juice.

Alwood *et al.* (1189) have made a study of the acid and sugar contents of the juice of a number of varieties of grapes. Table 70 is taken from their results with a column added for the characterization of the variety as given by Hedrick *et al.* (162).

It will be seen that in general with these Labrusca grapes, a large amount of sugar relative to acid is associated with high quality. Many other substances must enter into the determination of quality in grapes, such as the substance giving the foxy flavor characterizing such varieties

Table 70. Comparison of Total Sugar and Acid Results for Varieties of Grapes Analyzed during 1908–1911 and 1913, with Acid-Sugar Ratios

(Result stated as grams in 100 cc. of expressed juice)

Variety	Year	District	Number of Samples	Sugar as Invert	Acid as Tartaric	Acid Sugar Ratio	Quality
Agawan	1909	All northern	2	17.90	.840	1 : 21.3	Good
Brighton	1909	Northern Ohio	2	20.47	.632	1 : 32.4	Very good
Brilliant	1913	New Jersey	1	18.71	.676	1 : 27.7	Good
Campbell Early	1910	All northern	4	15.56	.884	1 : 17.9	Good
Champion	1910	New York	1	11.90	.915	1 : 13.0	Poor
Concord	1910	Northern Ohio	30	18.51	.757	1 : 24.4	Good
Conqueror	1913	New Jersey	2	12.98	1.074	1 : 12.1	Fair
Delaware	1911	New York	3	18.06	.916	1 : 19.7	Best
Diana	1909	Northern Ohio	1	19.90	.950	1 : 20.7	Good
Dutchess	1910	New York	3	17.48	.734	1 : 23.8	High
Elvira	1910	New York	4	14.23	1.253	1 : 11.4	Fair
Eumelan	1910	New York	4	17.80	.961	1 : 18.5	Above good
Herbert	1910	New York	1	16.54	1.200	1 : 13.8	Good to very good
Iona	1909	All northern	4	19.78	.836	1 : 23.7	Very good
Isabella	1913	New York	9	15.69	1.228	1 : 15.4	Good
Lindley	1910	New York	2	15.61	1.054	1 : 14.8	Good to best
Marion	1909	Northern Ohio	1	20.77	1.718	1 : 12.1	Fair
Martha	1909	New York	1	16.07	.840	1 : 19.1	Good to very good
Massasoit	1910	New York	1	15.21	.754	1 : 20.2	Good to very good
Niagara	1913	New York	6	15.96	.617	1 : 25.9	Good or above
Salem	1913	New York	2	19.64	.904	1 : 21.7	Very good
Winchell	1913	New Jersey	1	19.28	.506	1 : 38.1	Very good to best
Worden	1911	New York	2	13.12	.922	1 : 14.2	Good to very good

as Wyoming; that giving the musky flavor to such Vinifera varieties as Muscat Hamburg; that giving the vinous flavor to many varieties such as Delaware, Salem and Berckmans.

With the pear, it seems probable that the nature of the cell walls has much to do with quality; though, as with apples, the kind and amount of sugar and acid and perhaps other substances are important. With the more succulent fruits it would seem that the kind and amount of sugar and acid, flavoring oils, and other special chemical substances would be expected to play a larger part than would the rather small variations in the nature of the tissue.

The kinds of sugar and of acid in fruits are of importance in determining flavor. The relative importance of sucrose in apples has been mentioned. Thompson and Whittier (1364) have studied the sugar in some fruits. Their results are shown in Table 71.

TABLE 71. THE AMOUNTS AND KINDS OF SUGAR FOUND IN SOME OF THE DIFFERENT KINDS OF FRUIT JUICE

	PERCENTAGE IN JUICE			
	SUCROSE	FRUCTOSE	GLUCOSE	TOTAL OPTICALLY ACTIVE
Apple (Missouri Pippin)	4.26	4.65	1.06	9.97
Apple (Rubicon)	4.84	7.70	1.64	14.18
Peach	7.00	.47	.48	7.95
Peach (Belle)	7.10	1.44	1.44	9.98
Pear (Seckel)	1.57	7.46	3.62	12.65
Pear (Bartlett)	2.64	6.82	.75	10.21
Strawberry	.50	1.93	1.81	4.24
Banana	2.70	6.90	6.91	16.51
Plums (Grand Duke)	5.98	1.92	4.97	12.87
Quince	.25	5.46	2.01	7.72
Persimmon	6.30	3.61	3.61	13.52
Grape	none	5.06	4.56	9.62
(California)	.52	8.99	8.73	18.24
(Concord)	.54	6.90	5.36	12.80
(Niagara)	.37	7.06	8.87	16.30
(Catawba)	.45	8.91	7.54	16.90

Fructose was found most abundant in apples, pears, and quinces, sucrose in peaches and plums, while with the banana, the strawberry, the grape, and the persimmon fructose and glucose were present in nearly equal quantities as with "invert sugar."

Dunbar and Bigelow (1235) have studied the acids in different fruits. They found the acidity of plums, apples, cherries, peaches, and quinces apparently due entirely to malic acid, which, with the first three at least, seemed to be present mainly in the free state. Currants contain citric acid and may or may not contain malic acid. Gooseberries and cranberries contain both malic and citric acids. Pomegranates and red raspberries contain citric acid, apparently without malic acid. Blackberries they found to contain citric acid in some cases, while some samples contained traces of malic acid without citric, and in others neither malic nor citric acids could be identified. The acid of the apricot they did not positively identify, but found a dextrorotatory acid which, on account of the increase of its rotations by the addition of uranyl acetate, they thought might be tartaric or dextromalic acid. With pears, they found Kieffer, Le Conte, Idaho, and Bartlett to contain little or no malic acid, citric acid seeming to predominate; while with other varieties the acidity seemed to be due primarily to malic acid. Tartaric acid was not found in the fruits mentioned with the possible exception of the apricot. Sando and Bartlett (1339) found malic acid the predominant acid in fruits of the American crab apple (*Pyrus coronaria*).

Demoussy (1229) thinks that acids and sugars may be localized in different cells. When, by means of successively increased pressure, he expressed sap from fruit pulp that had not been killed by heating or freezing, he found with plums, apricots, peaches, and some other fruits that the concentration of acids and of reducing sugars was not as great in juice of the first pressing as in the juice liberated by means of increased pressure. The reverse was true with sucrose. He concluded that with these fruits the acids and reducing sugars are in the tissues with the stronger cell walls; the cell protoplasmic membrane thus being less easily ruptured by the pressure. He thinks that the reason apricots and some kinds of plums when cooked are so much more sour than the fresh fruits is because the killing of the protoplasm, in cooking, releases the acids; while in eating fresh fruits not many of the strong walled cells containing the acids would be ruptured. The pleasant sweet flavor of the fresh fruit, he thinks, is due to the fact that in eating it the larger number of the cells that are ruptured and from which the contents are released are the thinner walled ones containing the larger amounts of sucrose.

A slight astringency may sometimes be due to organic acids; but, as with the apple, it is probably generally due to some tannin compound. With some fruits, such as the persimmon, there may be a very unpleasant astringency until the fruit is ripe or even overripe. With some fruits, however, it seems to give a very pleasant flavor. In fact, with ripened persimmons that is true. The pleasant "vinous" flavor of some excellent varieties of grapes, such as Delaware, may be due to the presence of tannin compounds.

It should be emphasized again that with no fruit is our knowledge of its chemistry sufficiently complete for chemical analysis to give any accurate rating of a variety as to quality, or explain its characteristic flavor. Perhaps, with Citrus fruits in whose flavor sugars and acids are so dominant, this can be more nearly accomplished. However, in spite of this incomplete chemical knowledge, we know that harvesting and storage practices that influence the amounts of the different sugars and esters, and the acidity of the fruit will influence its flavor; and so analysis for these substances may be important as indicating the effect of a treatment on quality.

Little is known as to the effect on quality of other orchard practices than those at harvesting, or of other environmental features than temperature. (In fact, we are far from having exhaustive knowledge concerning the effect of harvesting practices, or of the temperature during growth and ripening, on the flavor of the different varieties of fruit.) We have seen that Rivière (886, 887) found a reduction in the sugar content of grapes when the canes were kept pinched back to less than five leaves beyond the last bunch of fruit; and that he found the sugar content of apples influenced by the method of training the trees. It seems probable that the sweetness of flavor may be influenced by orchard practices. If the soil water and nutrient supply are such that the tree is in a healthy condition, it seems that the larger the foliage relative to the amount of fruit tissue on the tree, the more sugar there may be in the fruit. This should be true especially of varieties that ripen early in summer before, or very soon after, wood growth ceases. Thus, it seems possible that with such early varieties, severe pruning, by prolonging growth and delaying the accumulation of carbohydrates in the tissue, might tend to reduce the sweetness of the fruit. I have known the quality of very early ripening varieties of peaches to be reduced in some way by the vigorous growth following severe pruning. On the other hand, with late ripening varieties under the same condition, pruning, by improving the water supply, might cause the fruit to be of larger size with greater tenderness of flesh, and yet, by the time of ripening, in spite of the pruning, the carbohydrate supply would probably be sufficient to give the maximum sweetness to the fruit. Thinning the fruit, by reducing the amount of fruit tissue relative to the leaf surface, might be expected to increase (though perhaps not measurably) the amount of sugar in the fruit left. Often with a summer variety of apple such as Sweet Bough, with which there will be fruit ripening normally on the same tree during a rather long period, the last fruits to ripen will possess the best flavor, being apparently much the sweetest. It may be that after much of the fruit is off the tree there is a greater accumulation of sugar in the tissue and that more will therefore move into the fruit.

Ripening and Gradual Breaking-Down of Fruit

Histological and chemical features that seem to determine or influence the quality of fruits at the optimum condition of ripeness have been discussed. Fruit that is to be put on the market is seldom or never at such a condition of ripeness when it is picked, but must go through a ripening process before it reaches maximum quality. In this process there occur, in the chemical nature of the cell contents, changes that affect the flavor of the fruit and, in the cell wall, changes that affect the texture. The fruit is in a measure at least a living thing. After it reaches maturity it contains apparently no cells that can be caused to divide; and so it can form no new tissue, not even a corky covering for wounds. The changes that take place are primarily those involved in breaking-down of materials; the fruit is destroying itself by its own processes.

Some of the processes are: the changing of starch to sugar; the inverting of non-reducing sugars; the loss of astringency due to changes in the tannin and perhaps also in acid; the forming and the breaking-down of esters; and the softening of the cell walls, due possibly to the changes in the pectin. Throughout the life of the fruit, too, respiration goes on, probably the most rapidly during the earlier ripening process.

Change of starch. Conversion of starch to sugar was observed in ripening bananas by Tallarico (1356), by Geerligs (1247), and by Gore (1251), who found the starch changed rather rapidly to sucrose during ripening, sucrose being later hydrolized to glucose and fructose. Browne (1212) gives the following analyses for starch in Baldwin apples: very green August 7th, 4.14 per cent of the green weight; green, September 13th, 3.67 per cent; ripe, November 15th, 0.17 per cent; overripe, December 15th, none. During the same period total sugar increased from 8.03 per cent, green weight, in very green apples to 14.51 per cent in ripe and 14.107 per cent in overripe apples. Bigelow, Gore, and Howard (1196) found that starch first disappears from the pith near the tips of the core wedges and continues until it has disappeared to the core line. The last tissues to lose their starch are the peripheral 1.5 to 3 mm. of the flesh and parts of the flesh extending fan-shaped from the primary vascular bundles (core lines). With Ben Davis and other winter apples, they found starch gone by November 5th. Thatcher (1361) could not find the enzyme diastase in ripening apples. He says that the diastase seems to disappear with the disappearance of the starch. He seems to have worked with apples ripe enough that there was no starch to convert. The ripe fruit does not possess the ability that some other tissues possess, to change sugars back to starch.

Changes of sugar. Of course, with nearly all kinds, there is an appreciable increase in sugar content as the fruit approaches ripeness and until most of the starch disappears. Rivière and Bailhache (1328) have recorded results of analyses showing such change in Chasselas Dore grapes and in a number of varieties of pears grown in France. Most of the change after the starch has disappeared must be a very slow reduction in total sugar content (Magness and Burroughs, 1286, and others) and a changing from a higher to a lower molecular weight such as a changing of sucrose to invert sugar. Thatcher could not find invertase in apple tissue, yet Browne (1212) found for Baldwin apples the results shown in Table 72.

TABLE 72. SHOWING AMOUNTS OF SUGAR IN RIPENING BALDWIN APPLES

		SUCROSE PER CENT OF GREEN WEIGHT	INVERT SUGAR PER CENT OF GREEN WEIGHT
Very green	August 7	1.63	6.40
Green	September 13	4.05	6.46
Ripe	November 15	6.81	7.70
Overripe	December 15	5.26	8.81

The inversion may be due to the acid present. In still another analysis he found in overripe apples a slight reduction in sucrose and an increase in invert sugar. Bigelow, Gore, and Howard (1196) in rather extensive work found similar results with Rhode Island Greening, Northern Spy, Winesap, and Ben Davis in common storage — temperature not given — and with Winesap and Ben Davis in cold storage — temperature 32° F. Studies by the same workers showed that with apples, from early summer to harvesting time, there is a rather rapid increase in sucrose as well as reducing sugars. All of these results indicate that, at least with some varieties of apples, the percentage of sucrose increases up to the time the fruit is edible (but a little too hard and, sometimes, a little too acid for best quality), and that from that time until it breaks down there is a reduction in sucrose and a corresponding increase in reducing sugars. Apparently the sucrose is being inverted. These results were with fruits at rather low temperatures; for the temperature, even in common storage, is generally lower than would be favorable for growth. Spoehr (318) has shown that there is a rather general tendency for plants to form polysaccharides at high temperatures and simple sugars like glucose at low temperatures. This may suggest that inversion of sucrose during storage is a result of the temperature. However, Magness (1282) could find with Bartlett pears no marked relation between the storage temperature and the relative amounts of sucrose and reducing sugars; and Bigelow, Gore, and Howard found inversion much the more rapid at the higher temperatures. With Ben Davis apples removed from cold storage January 1, 1903, and kept at about 70° F., sucrose was reduced more by April 13, 1903, than it was reduced by April 27, 1904, in apples of the same variety picked at the same time and left in cold storage (32° F.). This reduction in sucrose occurs mainly after starch has disappeared and increase in total sugar has ceased. With Bartlett pears, Magness found in California and Oregon that during a period of six to eight weeks before the fruit ripened on the tree there was a marked and rather uniform increase in the amount of sugars, not only in the amount found at picking time but also in the amount after the fruit ripened in storage. Early in the period the increase seemed to be the more largely in reducing sugars, while late in the period it was more largely in sucrose. He did not study the fruit after it had become overripe. Fruits stored at 40° F. never contained as much sugar as fruits ripened at 70° F., or as much as fruits held at 30° F. but removed while hard and ripened at room temperature.

It is not possible to say with how many kinds of fruits there is inversion of sucrose late in the ripening process or after they are overripe. It would be expected to occur at least with all acid fruits. Bigelow, Gore, and Howard (1196) found with peaches ripening on the tree that the total amount of reducing sugars and sucrose increased rather markedly between the times when the fruit was market ripe and fully ripe. With peaches kept in storage after picking, market ripe, the results were similar to those with apples though the increase in reducing sugars was less marked. In Table 73 (page 650) is a summary of their results. While the loss in sucrose was rather large at all temperatures, there was an increase in reducing sugars only at the highest temperatures, and apparently a considerable loss by those kept in the common refrigerator.

Tallarico (1356) and Gore (1251) found sucrose inverted in ripening bananas; and Geerligs (1247) found the same in mangoes, Lopez Dominguez (1281) found sucrose inverted after maturity with the grapefruit. Bigelow, Gore, and Howard (1196) studied the chemical changes in oranges during their later development on the tree and in storage. They began taking samples when the fruit was a little more than half of full size

TABLE 73. COMPARISON OF AVERAGE DAILY CHANGES IN PEACHES STORED UNDER VARIOUS CONDITIONS

(Percentages based on dry weight)

TEMPERATURE OF STORAGE	TIME OF STORAGE (days)	SOLIDS (per cent)	MARC (per cent)	REDUCING SUGAR (per cent)	SUCROSE (per cent)	TOTAL SUGAR AS INVERT (per cent)	ACID AS SULFURIC (per cent)	UNDETERMINED (per cent)
25°–30° C.	2–10	−3.117	−1.751	+1.601	−1.778	−0.271	−0.0403	−1.120
0° C.	28–63	− .2213	− .0173	+ .0241	− .2571	− .2471	− .0551	+ .0846
12°–15° C.	8–10	− .722	− .319	− .419	− .699	−1.153	− .085	+ .798

on July 31st. Fruit on the trees was still green over the surface October 5th, was about half colored October 30th, and was fully colored and separated from the tree readily December 15th. They found the percentage of acid and of marc (cell wall tissue) steadily decreasing during that time; an indication, they think, that practically all of the acid and of the cell wall tissue is formed early in the life of the fruit. The sugars they found to increase gradually during the life of the fruit, sucrose and reducing sugars being present in about equal quantities. During storage, at room temperature, of green or of ripe fruit there was a slight reduction in acid and total sugar contained; and the percentage of reducing sugars increased considerably, while that of sucrose decreased.

André (1191) noted that at harvest reducing sugars and sucrose are present in the orange fruit in about equal percentages; and that during storage there is generally a very slight decrease in acidity, an increase in reducing sugars and a relative reduction in sucrose. He found that inversion would proceed somewhat more rapidly in crushed than in normal tissue and that both citric acid and invertase were concerned in the inversion, the citric acid in the quantities present apparently being able to cause more rapid inversion than could the invertase in the quantities present. Naturally, inversion by citric acid was more rapid at temperatures above the normal; being very rapid at 100° C.

Change of acids. Fruits on ripening are generally less acid in flavor. Since the acidity in flavor of fruits is determined rather by the sugar acid ratio than by the acid content alone, we cannot say from flavor changes whether or not there is an actual reduction in acid content. Thompson and Whittier (1364) did not find any marked change in acid content of ripening fruits. Their tables suggest a slight decrease during ripening with strawberries and pears, and late in the ripening period with grapes, an increase with peaches and no consistent change with apples. Browne (1212) gives the following for malic acid with apples, August 7th, very green, 1.14 per cent of green weight; November 15th, ripe, 0.65 per cent; December 15th, overripe, 0.48 per cent. Bigelow, Gore, and Howard (1196) found with apples an appreciable reduction in acidity during the early stages of ripening and but slight reduction, if any, later. Magness and Burroughs (1286) found a large reduction of acidity of Baldwin and Winesap apples during ripening, the reduction being greater with Baldwin than with Winesap and considerably more rapid the higher the storage temperature. Conditions that favored rapid respiration hastened the loss of acid considerably more than it hastened the loss of sugar.

Rivière and Bailhache (1328) found the acid content reduced during ripening with the fruits of Chasselas Dore grape and fruits of a number of varieties of pears. Magness (1282) found with Bartlett pear that, in California districts, the acid content decreased considerably during the last five to eight weeks before it was fully mature on the tree; but at Medford, Oregon, it increased slightly, and at the higher latitude of Yakima, Washington, it increased markedly during the same period. Pears ripened in storage at 70° F. showed an increased acid content over that when picked; while pears ripened at 40° or 30° F. showed a reduction in acids. Fruits that ripened well on the tree showed little change in acidity during storage. Bigelow, Gore, and Howard (1196) found a reduction in acids during ripening of peaches and oranges; and Hawkins and Magness (1260) and Hawkins (1258) and Lopez Dominguez (1281) found a reduction in acids during ripening of the grapefruit. It seems generally true, but with some exceptions, that the percentage of acids in fruits is reduced during ripening. With plums in California, Overholser, in some unpublished work, found the percentage of acid rather strikingly reduced during ripening after being harvested, and considerably reduced on the tree between the times of the first and the third pickings.

Changes of odorous constituents. Study is needed as to the temperature and other conditions at ripening time that influence the nature of the odorous constituents developed. Casual observation suggests that those giving the most desirable flavor appear at the beginning of ripening; and, with many varieties in storage, tend to disappear long before the fruit becomes otherwise overripe. It is possible that these result from the metabolism in the fruit and that the temperature at which the fruit ripens may influence the amount developed. Thus, Grimes Golden apple does not seem to develop its highly odorous character unless ripened at rather high temperature. Thatcher (1361) found in ripening apples a small amount of esterase, suggesting the presence of an ester at that time. The breaking up of these odorous esters by this enzyme may account for the rapid loss of odor in storage by some highly aromatic varieties; or the oxidation in the tissue may cause it, the temperature at which the oxidation occurs being influential.

Loss of astringency. Most fruits while green are somewhat astringent and some are markedly so. During the ripening process this astringency is generally reduced. This may sometimes be due to changes in the acids other than tannic acid; however, it probably results much more often from changes in the tannin compounds through enzyme action. Thus, Vinson (1373) found that dates would not lose their astringency after being heated to 70° F., probably because the enzyme was destroyed by heat. Tannin is found in the ripe fruit of most, if not of all, varieties of apples. Bigelow, Gore, and Howard (1196) found it in considerable quantities in Northern Spy and Rhode Island Greening fruits in common storage as late as December 1st, there being then apparently as much as at picking time. Overholser and Cruess (1306a) found tannin throughout the tissue of Green Newtown apples apparently during the entire storage period. The tannin found in this fruit seemed to belong to the catechol or iron-greening group rather than the gallic acid or iron-bluing tannin. It is the oxidation of tannin that causes the browning of apple tissue exposed to the air. They seemed to find that this oxidation is dependent upon the presence in the tissue of a peroxidase and an organic peroxide. When either or both of these were destroyed the browning of a tannin solution would not occur unless the peroxidase and a peroxide were supplied. Exposing pared apples to sulphur fumes, they seemed to find, prevents browning by changing the organic peroxide. The peroxide was found to disappear upon reaction with the tannin; and it was more easily disorganized by heat than was the peroxidase. When the peroxide only was destroyed, adding hydrogen peroxide would cause the browning of apple tissue or apple juice. Apparently the browning results when, by injury, the protoplasm is rendered permeable and the tannin, peroxidase, and peroxide are permitted to mix. Onslow (1301) found a similar condition in a number of plant tissues but not in all fruits. Fruits of the apple, pear, and plum, the peel of banana fruits and, to a much less extent, the pulp turned brown after injury; while fruits of the orange, lemon, lime, and raspberry did not. These last seemed to contain neither the organic peroxide nor the catechol tannin. Tannins are among the substances that give character to apple cider. As to whether or not the reduced flavor of cider from overripe fruit is due to tannin changes, I do not know.

The tannin compounds of different fruits are probably not the same.

It seems probable that astringency may be lost or reduced by changes of tannin compounds to less soluble forms; but according to Griebel and Schäfer (1255) it seems to be more often lost by the coagulation of a colloidal substance in which the tannin is included. They observed, within cells of some fruit tissues, special tannin containing bodies which they called inclusions. These inclusions tend to coagulate and thus to hold the tannin from solution. A loss of the acrid flavor and some of the acidity of flavor at ripening is due, they say, not to a loss of tannin, but to its being held by the coagulation of the substance containing the tannin. They say the mesocarp of a number of fruits, chiefly varieties of pears, is composed almost entirely of this tannin holding colloidal substance. They found such "enklusen" in all the fruit of all well-known species of pears, in that of *Pyrus baccata* and in that of *Prunus spinosa.* It seems that astringency may be reduced also by reduction in the amount of tannin in the fruit. Overholser and Cruess (1306a) say that the amount of tannin may be reduced by oxidation in the tissue, and that by exposure to the air the tannin of apple tissue is changed by oxidation and condensation to a dark red insoluble substance. Geerligs (1247) found marked reduction in tannin in ripening sapodillas. If the vinous flavor of some varieties of grapes such as Delaware is due to tannin, that substance remains in them until they are very ripe.

Japanese persimmons are very astringent, due to the tannin they contain in large special cells. On becoming so ripe that they are soft, this astringency is generally lost. According to Fairchild (1239), the contents of these cells become hardened at that time, so that they are not affected by water. According to the observations of Lloyd (1278) the vacuoles of these cells are filled with a mucilage-like carbohydrate substance of the nature of cellulose (which he calls x-cellulose) in which the tannin is loosely adsorbed. This x-cellulose has great power of absorbing water and swelling until late in the ripening process of the persimmon when it becomes coagulated and adsorption of the tannin is more nearly complete. As the x-cellulose becomes more completely coagulated, less and less of the tannin can escape into other water of the tissue; and the tannin flavor of the persimmon thus becomes so reduced that it is not objectionable. With some varieties, fruits containing seeds lose astringency more rapidly than do seedless fruits and have a flesh of darker color. Lloyd found that the process of coagulation in the tannin cells is hastened by the presence of seed in the fruit, and the darker color of the flesh of fruits containing a number of seeds (or the dark color of flesh around the seed of fruit containing a few seeds) is due to oxidation of the tannin after the death of the tannin cells.

Loss of astringency can be brought about artificially before the flesh becomes soft. The fruit is then much more desirable. The Japanese accomplish this by means of alcohol vapor; placing the fruit in sake (rice wine) kegs until the astringency is lost. Gore (1250) found that keeping Japanese persimmons in carbon dioxide for from three to five days renders them non-astringent, and leaves them in better condition than when processed by the Japanese method. The fruit remained firm after being processed in carbon dioxide; but ripening was hastened. In some large scale experiments Gore found that at temperatures prevailing in Florida, Triumph required $1\frac{2}{3}$ to $2\frac{1}{2}$, Imperial $4\frac{1}{2}$, Hachiya 7, Okame $4\frac{1}{2}$, Tanenashi 7, Zengi 2, Costata 4, Hyakume $1\frac{1}{2}$, and Yemon $1\frac{1}{2}$ days to become non-astringent in carbon dioxide. Shipping quality of the fruit was somewhat impaired by the treatment. American persimmons were not rendered non-astringent by this process. While tannin is the cause of the astringency of many fruits, we may not be justified in assuming that it is the only source of astringency in fruits. Slight astringency might be due to other organic acids than tannic acid.

Changes in pectin. The softening of the ripening fruit has been thought to result from the changing to pectin of an insoluble pectic substance in the cell walls that gives rise to the soluble pectin. Pectin, according to Mangin (1288) and others, is very common in the cells of plants, particularly in the middle lamella, which consists largely of such substances. It is found also intermixed with the cellulose of the other layers. With fruits, such as the peach, whose cells are large with thin walls, when these hard pectic substances are changed to a soluble form the fruit becomes very soft. With apples the cell walls are thicker and the solution of the pectin may not render the fruit very soft. It may become "mealy" or granular in texture and lose flavor. We have seen that Bigelow, Gore, and Howard (1196) called attention to the fact that this may be important in the loss of flavor by some varieties of apples during storage. Due to the solution of the middle lamella the cells are easily separated from each other. The cells are, therefore, not readily ruptured in mastication, and the flavored juices are not released. However, pectin of the apple is thought by Tutin (1371) to be a specific compound not necessarily derived from an insoluble pectic substance. Its solubility may depend upon the chemical composition, particularly the hydrogen ion concentration, of the surrounding medium. Ions such as calcium magnesium or various organic groups attached at positions in its molecule may affect its solubility. Ehrlich (1236) seemed to find its molecule to contain primarily arabinose, galactose and galacturonic acid; the galacturonic acid being the important constituent to which the other groups are attached. Von Fellenberg (1241a) regarded pectin as the methyl ester of pectic acid; the methoxy groups being the characteristic part of the molecule. Tutin (1370) thinks apple pectin may be the dimethylisopropenyl ester of pectic acid.

Pectin is of peculiar importance in the making of fruit jellies, since the property of setting or gelatinizing of fruit juices is due to the small quantity of pectin present. With apples, at least, there is so little pectin in the ordinary cider that no satisfactory jelly can be made; but if the tissue is killed, by heat, or by freezing, before the juice is expressed enough pectin is released to obtain firm jelly. With some fruits the pectin is not of a form that will coagulate into a gel upon the cooling of a concentrated solution containing sugar. It may be that this is due to an unfavorable hydrogen ion concentration. Tarr (1357) found that, while jelly formation is not closely correlated with total acidity, it is closely correlated with active acidity; the minimum hydrogen ion concentration at which apple pectin will form jelly being pH 3.46, the jelly becoming firmer with increase in hydrogen ion concentration to pH 3.1, at which concentration there is a seeping out of the liquid contents. At much higher concentration jelly is not formed. In making jelly, the amount of sugar used influences the texture, too much sugar causing the jelly to be weak and too little causing it to be tough. Tarr and Baker (1357a) found that the amount of sugar that can be added, without injuring the quality of the jelly formed, is determined by the hydrogen ion concentration. More sugar can be added when the hydrogen ion concentration is near pH 3.1 than when it is near pH 3.46. The amount of sugar added does not influence appreciably the percentage of sugar in the jelly; but the amount of jelly obtained from a given amount of pectin is determined by the amount of sugar added. The amount of good jelly that can be obtained from a given amount of pectin is therefore determined by the hydrogen ion concentration of the solution.

With the apple, pectin is of great importance for jelly making; and extracted pectin is coming to be of considerable importance in commerce. Haynes and Judd (1262) found that from tissue that has been killed by a temperature obtained by use of a freezing mixture, such as salt and ice, pectin is extracted as readily as from tissue that has been killed in liquid air. However, a large amount of the pectin is held in the pulp unless it is washed and pressed several times. Carré (1214, 1215) seemed to find that there is in the tissue an insoluble pectic substance, called by her protopectin, and by earlier writers pectose, from which soluble pectin can be derived by hydrolysis with weak acid. Before the fruit begins to ripen there seems to be no soluble pectin; but during ripening it rapidly becomes soluble. Tutin (1371) does not think there is necessarily a protopectin or other insoluble pectin compound. He thinks that the reason Carré was able to derive by means of weak acid large quantities of pectin from the tissue after it ceased to yield water soluble pectin is that the tissue was not sufficiently disintegrated. When he ground the tissue and extracted pectin by means of water and pressure, he was able in each of two or more grindings with sand to extract rather large quantities with water alone. After such repeated grinding finely with sand and extracting with water, acid hydrolysis of the marc remaining yielded very little pectin. However, Sucharipa (1355a) finds that in the white pericarp of the lemon there is a protopectin that yields pectin and cellulose when hydrolyzed.

If there should be no protopectin or pectose in the apple, it would be interesting to know what causes the weakening of the middle lamella of the cells as the fruit becomes overripe. It seems possible, though not certain, that a change in active acidity might have that effect.

Respiration. Oxidation proceeds during the entire life of the fruit; but, other conditions being the same, it is most rapid at ripening time. At least, that is true of bananas (Gore, 1251). Oxidation seems to be the most important process in the overripening and final breaking down of fruit. Much study has been given to the subject of aerobic and anaerobic respiration as affecting the transportation and storage of fruits. An exhaustive review of the literature on respiration does not seem necessary. Browne (1212) found that apples removed from storage on November 27th and held eighteen days lost 6.66 per cent in weight, yet there was no appreciable change in moisture content; and Morse (1294) found that, while fruit held in cold storage from November 13th to July 1st lost 4.71 per cent in weight, the moisture content was not reduced. Magness (1284) found that the respiration of Bartlett pears was about twice as rapid at 37° F. as at 30° F. Burroughs (1213) studied the rate of respiration of Wagener apples at different temperatures with the results shown in Table 74. He found that Wagener and Baldwin apples picked while

TABLE 74. EFFECT OF TEMPERATURE ON THE RAPIDITY OF RESPIRATION OF APPLES

MEAN TEMPERATURE		MILLIGRAMS OF CO_2
Degrees F.	Degrees C.	TO THE KILOGRAM HOUR
32.5	0.25	3.10
40.2	4.55	5.05
48.3	9.05	7.50
68.5	20.20	11.96
86.0	30.00	24.37

immature and stored for a period of four to fifty-seven days at 32° F., seemed to respire more rapidly when placed at 68.5° F. than did apples placed in the 68.5° F. room when picked.

Magness and Burroughs (1286) found with Winesap and Baldwin apples respiration about fifty per cent more rapid at 35° F. than at 32° F. Baldwin grown in New York respired more rapidly than Winesap grown in Washington. Perhaps the thicker waxy covering of the Winesap grown in the absence of summer rainfall reduced the oxygen supply to the tissue. Wounding the fruit, particularly breaking the skin, greatly increased respiration. Magness and Diehl (1287) found that coating the fruit with paraffin or oil reduced the rate of respiration at 32° F. and at 64.5° F. At all temperatures the amount of carbon dioxide evolved by uncoated fruit was about equal to the amount of oxygen consumed, which suggests that there was no anaerobic respiration. With coated fruit at 32° F., and at 64.5° F., the amount of carbon dioxide evolved was a little greater than the amount of oxygen consumed; while at 80° F. it was much greater. The coating seems to have caused some anaerobic respiration.

Carrick (1216) found with Red Emperor grapes and Yellow Newtown apples that respiration was about thirty to thirty-five per cent less rapid at −2° C. than at 0° C., and about forty to forty-five per cent less rapid at −3° C. than at 0° C. At −3° C. there was some ice in the tissue. Yet respiration continued without measurably greater reduction than an equal lowering of the temperature without ice formation should have caused. It would be expected that lowering the temperature would reduce the rate of respiration as it would reduce the rate of other chemical reactions.

Carrick froze McIntosh apples at −7.5° C. for three, six, and twenty-one hours and, after they were thawed, studied their rate of respiration at 20° C. Those frozen twenty-one hours were entirely killed and oxidation with them was very slow. A few cells were killed in the apples frozen only six and three hours; but after thawing their respiration was more rapid than that of unfrozen fruit.

Gore (1249) studied the rate of respiration of many fruits and gives the following summary:

> Plums, apples, and pears were less active than peaches. Summer apples respired with perceptibly greater rapidity than the winter varieties. The Concord, Delaware, Niagara, and Catawba grapes were found to be distinctly more active than the Vinifera grapes, Flame Tokay, Black Cornichon, and "Almeria," or the Rotundifolia variety James. Mangoes were nearly as active as peaches. The citrus fruits were exceedingly inactive.

> No satisfactory theory based on the composition or size of fruits has been found to account for the differences in the respiratory activity. A few moments' inspection shows that the rate of respiration is not a direct function of content of sugar or of acid, and does not depend upon size, as Japanese persimmons are richer in sugar than strawberries, yet are less active; oranges and lemons, which differ greatly in acid content, have about the same respiratory activity; red currants differ greatly in respiratory activity from black currants, although they are nearly the same in size. Generally speaking, the fruits which have a short growing period, mature rapidly, and become overripe quickly — as strawberries, and blackberries — are very active physiologically. At the other extreme are the slowly developing citrus fruits, which are very inactive. Intermediate in these respects are the other fruits. Peaches have a shorter life history than apples and are more active. Summer apples do not keep so well as winter apples, and respire more rapidly.

Gore found no difference in respiration of fruit before and soon after picking; though Burroughs found with apples a considerable increase in respiration after the fruit had been off the tree for a few days.

Hill (1264) studied the respiration of fruit in hydrogen, in nitrogen and in air, and, of a few, in carbon dioxide. He found anaerobic production of carbon dioxide as great as aerobic in ripe cherries, blackberries, and grapes, though green peaches respired more than twice as actively aerobically as anaerobically. This suggests that only ripe fruit respires as actively anaerobically as aerobically. When oxygen was excluded from green fruit for a few days and the fruit was brought back into the air, the rate of production of carbon dioxide did not entirely return to the normal. Ripe apples kept in oxygen free air long enough lost color and flavor and acquired the appearance of half-baked apples. Peaches in nitrogen and hydrogen became brownish and acquired a bad flavor; those in carbon dioxide remained hard and green longer than the others; but they acquired a very bad flavor and turned brown rapidly soon after being placed in the air.

Thatcher (1361) found the ripening process of Alexander apples inhibited when they were kept in an atmosphere of carbon dioxide. This could not be due entirely to lack of oxygen; for when the fruit was kept in nitrogen or hydrogen it went down very rapidly. Hill suggests that carbon dioxide may inhibit the hydrolysis of pectose. Thatcher did not find the quality of Alexander apples noticeably injured after nearly six months at room temperature in an atmosphere of carbon dioxide, though apples in the air at the same temperature became overripe in about four weeks; those surrounded by oxygen apparently a little sooner; while those surrounded by hydrogen and by nitrogen became discolored and unhealthy in appearance in four weeks and broke down to a mushy mass in about eight or ten weeks. Kidd and West (1272a) say, without giving their data, that they seemed to find that up to a certain concentration carbon dioxide retards the ripening of fruits without causing injury; though concentrations as high as 13.6 per cent of the atmosphere surrounding the fruit may cause serious injury. Magness and Diehl (1287) found a slight flavor of fermentation in apples after storage in an atmosphere containing twenty per cent carbon dioxide, fifty per cent carbon dioxide causing the fruit to be inedible and five to ten per cent causing no injury to the flavor. At all these concentrations the softening of the fruit was markedly inhibited.

Overholser and Cruess (1306a) found that Yellow Newtown apples stored in nitrogen under five to ten pounds pressure during one month, (one lot at room temperature and one at 32° F.) were not injured in appearance or flavor. The oxidizing system which they were studying (peroxidase and organic peroxide) was uninjured in the nitrogen. In fact, it seemed more active than with apples stored in air. Yet when fruits were stored in carbon dioxide, hydrogen, or oxygen, the organic peroxide seemed to be destroyed. At least the tissue would not show the reaction indicating the presence of that substance (it would not turn blue a mixture of potassium iodide, starch, and acetic acid or a mixture of potassium iodide, starch, and ferric sulphate). However, fruits stored in carbon dioxide and in hydrogen turned brown rapidly when exposed to the air; and fruits stored in oxygen were brown when removed from the containers. The authors think that the carbon dioxide and the hydrogen caused the protoplasm to be more permeable and that the browning was caused by the oxygen of the air. Later Overholser, in some unpublished work, found that when Green Newtown apples were stored in nitrogen not under pressure, the results were in agreement with those of other workers; but when the nitrogen was under ten to fifteen pounds pressure, both the firmness of the fruit and its quality were retained better than with fruits in a cold storage room at 32° F., the fruits in nitrogen also being at 32° F.

It is evident that, as a result of oxidation in the tissue, it must eventually break down. Since this and other processes, such as the inversion of sucrose, proceed more rapidly at rather high temperatures, fruit is held at as low temperature as possible in order to delay the process of breaking down. However, not only does this oxidation process contribute to the ultimate breaking down of the fruit; but the oxidation products must greatly influence the flavor. It is not impossible that some of the odorous constituents are products of this process. Thus Babcock (1192) says that organic acids, aldehydes, alcohols and esters may result from the incomplete oxidation in intromolecular respiration. On the other hand, their disappearance from the fruit may be a result of it. The temperature at which the fruit ripens should influence the nature of the oxidation products, and, therefore, the flavor. That the ripening temperature may influence the flavor is conclusively shown by the work of Lewis and his associates (1276, 1277) with the Bosc pear. They found that this fruit will not reach maximum flavor in cold storage, but must go through part of its ripening process at a temperature as high as 61° F. The Grimes Golden apple seems not to acquire its characteristic flavor when ripened at low temperature. This may possibly be due to the effect of temperature on respiration products.

Magness (1283) has published data that suggest the possibility of a great influence of storage temperature on the quality of fruit as influenced by respiration. He studied the composition of the gas in the intercellular spaces of apples held at different temperatures. Precaution was taken to have good circulation of air around the fruit. His results are shown in Table 75.

TABLE 75. ANALYSIS OF GAS IN INTERCELLULAR SPACES OF GREEN NEWTOWN APPLES

TEMPERATURE OF STORAGE °C.	NUMBER OF DETERMINATIONS	PER CENT CO_2	PER CENT O_2	PER CENT CO_2+O_2	PER CENT N_2 BY DIFFERENCE
2	5	6.7	14.2	20.9	79.1
6	30	8.4	12.9	21.3	78.7
11	27	12.2	10.7	22.9	77.1
20	31	17.2	5.5	22.7	77.3
30	29	21.4	3.2	24.6	75.4

The proportion of carbon dioxide is much greater and that of oxygen much less at the higher temperatures. Similar results were obtained with potatoes; and Kidd and West (1272a) found such results with Bramley's seedling apple; though the increase in carbon dioxide with increasing temperature was less striking. Magness and Diehl (1287) found anaerobic respiration just beginning with Rome Beauty apples coated with oil when the carbon dioxide content in the intercellular atmosphere had reached about sixteen per cent and that of oxygen had fallen to about two per cent. It seems that it should be the carbon dioxide and oxygen contents of the gas surrounding the cells rather than of the gases surrounding the fruit that would be most important in determining the respiration products and the effect of respiration on the quality of the fruit. When the ill effect on flavor of holding the fruit in an atmosphere of carbon dioxide is considered, this work of Magness suggests that ripening at temperatures as high as 70° F. might injure the quality of fruit. We know from experience that with some varieties, if not with many, the reverse is true. It seems improbable, however, that with this great variation in oxygen supply and the probable difference in the amount of anaerobic respiration, there would not be differences in oxidation products that would affect the flavor favorably or unfavorably.

Changes in water content. It has been suggested that when fruit loses weight in storage, this loss is not always associated with a reduced moisture content. Of course, there is loss of water from the fruit, but it is conceivable that this might be counterbalanced by loss of dry matter in respiration. Babcock (1192) has found that the percentage of water may actually increase, due to the formation of metabolic water. Thus, he found with three varieties of pears, with apples, with plums, and with Japanese persimmons that, as they ripen after picking, the moisture content increases. Table 76 from Babcock shows the effect of anaerobic respiration in an atmosphere of CO_2 on the moisture content.

TABLE 76. WATER CONTENT AND LOSS IN WEIGHT OF SECKEL PEARS IN CARBON DIOXIDE

MONTHS EXPOSED	PER CENT OF WATER	PERCENTAGE LOSS IN WEIGHT	GRAMS OF DRY MATTER TO 100 GRAMS OF FRESH FRUIT
0	80.71		19.29
2	85.38	2.37	14.27
13	85.84	5.87	13.33

It is clear that the loss in dry matter is greater than the loss in weight. There was an actual increase in the amount of water in the tissue.

At Cornell University at different times apples were picked green or ripe and hung in a tree on the sunny side, or placed in an office or in storage with no protection from evaporation. The results of these are shown in Table 77.

TABLE 77. MOISTURE CONTENT OF APPLES WHEN PICKED AND AFTER BEING KEPT A CONSIDERABLE LENGTH OF TIME

	MOISTURE DETERMINATIONS
Fallawater apples when picked October 18	87.564±.038
Fallawater apples kept in warm office 2 days	87.781±.064
Fallawater apples kept in warm office 25 days	87.114±.108
Fallawater apples (wrapped) kept in warm office 25 days	87.251±.124
Fallawater apples kept in common storage 25 days	87.871±.121
Fallawater apples (wrapped) kept in common storage 25 days	87.825±.076
Fallawater apples kept in cold storage 25 days	87.737±.059
Fallawater apples (wrapped) kept in cold storage 25 days	87.792±.074
Fallawater apples kept in common storage 63 days	87.839±.062
Fallawater apples (wrapped) kept in common storage 63 days	87.946±.138
Fallawater apples kept in cold storage 63 days	87.610±.106
Fallawater apples (wrapped) kept in cold storage 63 days	87.862±.096
Fallawater apples kept in cold storage 149 days	87.715±.080
Fallawater apples (wrapped) kept in cold storage 149 days	87.842±.081
Young Tompkins King apples picked 8.10 P.M. July 18, and moisture determinations made at once	88.994±.038
Young Tompkins King apples picked 8.30 A.M. July 19, and moisture determinations made at once	89.572±.072
Young Tompkins King apples picked 8.30 A.M., and hung in tree until 5.00 P.M. July 18	90.000±.072
Young Tompkins King apples picked 8.20 A.M. July 13, and hung in tree until 5.00 P.M. July 18	90.702±.154
Tompkins King apples picked 9.15 A.M. Aug. 29, and moisture determinations made at once	88.468±.142
Tompkins King apples picked 9.15 A.M. Aug. 29, and hung in tree until 4.00 P.M	89.178±.087

Nearly all fruits have gained in moisture percentage for a time. Those held for long periods may finally have a reduced moisture percentage. Babcock thinks this increase in moisture percentage is from metabolic water. That seems to be the true explanation; for it does not seem probable that fruit hung up in the sun or kept in a steam-heated office could take up more moisture from the air than it transpires. Of course, loss of dry matter in respiration will tend to increase the percentage of water unless water also is being lost. But in Table 76 the loss of dry matter was greater than the loss in weight, indicating that water had been added in some way.

It does not necessarily follow that the amount of free water in the ripening fruit is greater than in the green one. Thus, as Babcock suggests, many of the chemical changes in ripening are hydrolytic and cause liquid water to disappear. It is possible that changes in the pectic substances and other substances may be of such a nature that more water is adsorbed. Thus, even when fruit shows slight wilting its percentage of water may not be reduced, but more of the water may be adsorbed. Of course, there is less free water when the fruit wilts. These changes in water relation may be of much importance as influencing the quality of the fruit by affecting its texture or its succulence.

It will be shown in the next chapter that notwithstanding what is said here, wilting is often a source of great loss in storage, the amount of water lost being greater than that formed in the tissue.

Summary. Except in the pith region of pome fruits, there is in the tissue of fruits a very intricate network of fibrovascular bundles. Perfection of development of these, as influenced by varietal characteristics and by the environment of the tree, influences the susceptibility of the fruit to certain blemishes that develop during or preceding storage.

The pigments that seem generally to be responsible for color in fruit are carotinoids and anthocyanins. Carotin does not require the influence of direct sunlight on the fruit for its accumulation there. With some fruits this is true also of anthocyanins. However, with others such as the apple, the pear, and the peach, the red color, due presumably to the presence of an anthocyanin compound, does not develop except when the fruit is exposed to direct sunlight. As to whether or not the amount of red color in the fruit is ever influenced directly by the extent of accumulation of carbohydrates in the tissue, there seems to be no satisfactory evidence.

Pleasantness of flavor in fruit is due to its texture, which is influenced largely by the nature of the cell walls (insoluble solids); to the amount and kinds of sugars and acids present; possibly partly to the ratio of sugars to acids; to the ease with which the cell juices are released when the fruit is eaten; to odorous constituents or esters; to astringent materials such as tannins; and perhaps to other features that have not been studied.

During the ripening of fruit the starch is all or nearly all changed to sugar; and after the starch disappears there tends to be a reduction of the amount of sucrose and, for a time at least, an increase in the amount of reducing sugars, coupled with a gradual reduction in the total amount of sugar. The percentage of acid in fruits is generally reduced during ripening; but, with pears at least, there seem to be some exceptions. Little is known concerning the changes in odorous constituents. With some varieties the temperature at which the fruit ripens and is stored seems greatly to influence the aroma developed and held. Many fruits tend to lose astringency, or to have their astringency greatly reduced during ripening, by the coagulation of a substance in which the tannin is held. The astringency of Japanese, but not of American persimmons, can be removed by holding for a few days in alcohol vapor or in carbon dioxide. The browning of injured tissue of some fruits such as the apple and the pear seems to be due to oxidation of tannin compounds. Changes in the pectin in the cell wall seem to influence the firmness and texture of the fruits; and, perhaps, the flavor. When changes in the pectin cause the cells to separate easily, fewer of them may be ruptured and less of the fruit juice may be tasted during mastication. Oxidation, which may be approximately the same as the respiration of normal plant tissue, proceeds continuously in fruit tissue. With anaerobic oxidation, such as that occurring when the fruit is stored in inert gases, the effect on flavor may be different from that of oxidation with fruit stored in air. However, there is conflicting evidence as to the effect of storing fruit in nitrogen and in carbon dioxide. The temperature at which the fruit is stored seems greatly to influence the percentage of carbon dioxide in the gas in the intercellular spaces of the fruit.

When fruit is picked from the tree, green or nearly ripe, its percentage of water may increase during a few days. This does not seem to be due entirely to loss of dry matter. It appears to be due partly to the formation of metabolic water. A fruit that has become wilted in appearance may have as high a water percentage as when it was turgid. This may be due to changes in the nature of the tissue such that more water is absorbed.

CHAPTER 26

HARVESTING, TRANSPORTATION, AND STORAGE OF FRUIT AND CARE AFTER REMOVAL FROM STORAGE

For the man who grows his own fruit, except with kinds that can be kept for winter, the problem as to picking is simple. With much the larger percentage of varieties the quality is better the riper the fruit becomes before it is picked; though this may not be true with some varieties. However, with fruit for the market, the degree of ripeness permitted on the tree will be influenced by the distance it must be shipped, the wholesale and retail marketing practices, the facilities for cooling it quickly, and the time it must be held in storage.

The transportation of fruit presents many problems similar to or closely associated with storage problems. Such an obvious matter as the importance of avoiding bruising need not be discussed here. The feature of transportation that requires special consideration is the temperature at which the fruit is exposed. Fruit for shipment is picked while still hard; and goes through the ripening and gradual breaking down processes described in the previous chapter. The lower the temperature, the more slowly this ripening proceeds. The refrigerator cars in common use, where the temperature is lowered by means of bunkers of ice at each end and is kept low by the insulation of the car, do not need detailed description here. The defects of the system are that the fruit is not cooled quickly enough and that the temperature is not uniform throughout the car. Circulation of the air through the cars and its cooling by contact with the ice bunkers is facilitated if the cars are constructed with false floors to permit air passage under the fruit, and with solid break heads except for air passages at the top and the bottom, and if in loading air channels are left between the rows of packages in the car. With ice alone the temperature does not go low enough; sometimes 100 to 200 pounds (two to four per cent) of salt is added when icing and re-icing; but, according to Ramsey (1321), if this practice is continued after the car has been *en route* more than forty hours, there may be a little danger of freezing of the fruit next to the bunkers. The slow cooling of unsalted cars is illustrated by records kept by Ramsey with a car of red raspberries that started from Puyallup, Washington, on August 11, 1913. The temperature of the lower tiers of fruit averaged 60° F. on starting and was at

34° F. in about forty-two hours, when it began to rise. That for the top tiers started 64° F. and was at 51° F. in about forty-two hours. After twelve hours the temperature of the lower tiers was 45° F. and that for the upper 61° F. Naturally the fruit ripens considerably before the lowest temperature is reached; and there may be much loss in the upper tiers if the shipment is over a great distance.

Cooling the fruit before it starts (precooling) is a promising means of avoiding some of this loss. The expense of the practice seems to be repaid, in the case of valuable fruit of a perishable nature that must be hauled for considerable distances. Two general methods of precooling the fruit are in use, car cooling and warehouse cooling. By the first method, air at about 22° F., or lower, is fanned through a large pipe into the car until the fruit is at the desired temperature. Very large plants are required for this method and cars from neighboring shipping points must be brought to a central point for cooling. Sometimes this may cause delays in cooling the fruit and in shipment. Care must be exercised to avoid freezing the fruit next to the cold air inlet; and it is difficult to cool the fruit in the car uniformly. Interest in this method seems to be declining. By the warehouse method the fruit is placed in the storeroom until the desired temperature is reached; air temperatures in the storerooms generally being considerably below that desired in the fruit, the cold air being fanned into the precooling room from another or the air in the room being kept in circulation by fanning. In many cases good results are obtained by pre-icing the car so that the temperature is rather low when the fruit goes in; placing about two hundred pounds of salt with the ice in the bunkers as soon as the car is loaded, or before, hastens the cooling.

In the storage of fruit it is desired to prolong as much as possible the ripening and to delay the breaking-down processes, and also to reduce to the minimum the development of rot-producing organisms and non-parasitic diseases. Generally, though with some exceptions, this is accomplished by maintaining the storage room temperature as low as possible without freezing the fruit. With nearly all fruits a temperature of 32° F. or slightly lower is desired. A few fruits, such as the banana, must be held at higher temperatures and with some, such as varieties of the Vinifera grape, that do not freeze until temperatures as low as 26° to 27° F. are reached, better results seem to be secured if they are held at a temperature as low as 28° F. (Carrick, 1216). It is not impossible that some fruits might be held in a slightly frozen condition without injury to quality. Carrick (963a) found with some varieties of apple that even slight freezing that does not kill the tissue seems to give a mealiness of texture, and a slightly reduced resistance to mold; but with Wagener apples there was very little mealiness six months after they had been held thirty days at 0.5° C. below their freezing point. Possibly with some varieties colloidal substances in the cell wall are more easily disorganized permanently than are those in the protoplasm. Some fruits such as the peach, the apricot, the Labrusca grape, the plum, the strawberry, the red raspberry, and the loganberry are killed by very slight ice formation: and ice forms at temperatures but slightly below the freezing point of water. With such fruits, a temperature lower than 31° F. is dangerous.

Powell (1312) says that storage does not influence the quality of fruit. However, from what we have seen concerning the effect of temperature on oxidation products, it seems probable that the storage temperature may appreciably influence the flavor of some fruits. This is a difficult problem to study because, as yet with most fruits, flavor cannot be expressed in chemical standards; and actual tasting is not satisfactory because fruit ripened at low temperature is not at the best stage of ripeness simultaneously with that ripened at high temperatures. Therefore, they cannot be sampled at the same time; and standards of flavor are not easily kept in mind during several weeks or months.

The holding of perishable fruits in a frozen condition for long periods at a temperature much below that which kills the tissue is coming to be of considerable importance. They are used for seasoning frozen desserts; but perhaps the largest use is for pies. When the fruit is kept for flavoring at soda fountains it is generally held in syrup and need not be kept at very low temperature. For pies and other uses to which fresh fruit or canned fruit may be put it is generally held without syrup and the temperature should be as low as −5° to +15° F., the temperature of 0° F. being preferable. The fruit is exposed to a cooking temperature at once upon thawing. Thus are avoided the chemical changes that are injurious to quality and that normally follow thawing of tissue that is frozen to death. Sour cherries, strawberries, red and black raspberries, blackberries, loganberries, currants, blueberries and huckleberries may be used for this purpose, the sour cherry being most important. It is said that fruit held in this way is better for pies and pastries than is canned fruit. Cruess, Overholser, and Bjarnason (1225) found that apricots and sweet cherries held at a temperature of 8° to 12° F. kept a better flavor if, during freezing, they were placed in water or in a syrup. The benefit of freezing in water was not so great with strawberries, though there seemed to be some benefit. Berries generally held their flavor in open crates better than did the other fruits. These workers found with the fruits mentioned that after being held at 8° to 12° F. they were better for pastry, ice cream and soda fountain purposes than was cooked fruit. A light syrup is more effective in preventing browning after thawing than is water alone.

Carrick (1216) found that peaches and plums do not retain a good flavor but become oily or slippery when held frozen; but that, if one pound of sugar is added to each two pounds of fruit, oiliness is not developed and an excellent flavor is retained, if the fruit is held in air-tight containers at 20° to 28° F. At these temperatures it does not freeze but can be kept indefinitely. Overripe pears are sometimes frozen by preserving companies and used at convenience. Such pears seem to make good preserves. Overholser has found that figs, and Overholser and Creuss (1306) found that some other kinds of fruits, can be held at low temperatures, 8° to 12° F., in sugar solution and that they retain their fresh flavor very satisfactorily. Even berries which are satisfactory for holding at such temperatures in open crates will hold up longer after thawing and retain a better appearance when held frozen in sugar solution. However, sour cherries and berries, especially raspberries and loganberries, are held satisfactorily in storage rooms at a temperature of 0° to 10° F. without syrup or water and do not discolor.

Cruess, Overholser and Bjarnason found that grape juice held at a temperature of 8° to 12° F. for nearly eight months, retained a much better flavor than that of pasteurized juice. Gore (1248) found apple cider and other fruit juices of higher quality when concentrated, by freezing and throwing out the ice crystals by means of centrifugal force, than when preserved by heat. He also found the quality of apple cider improved by being held in cold storage.

Pomologists have found it necessary to give much attention to engineering or architectural features of the storage houses. It does not seem wise here to depart so far from the responses of the fruit as to go minutely into a study of such investigations. Two general types of storage are of commercial importance, the mechanical refrigeration plant, in which the temperature may be controlled rather accurately, and the common storage house, where temperature regulation is by insulation and ventilation. It is evident that in the common storage house the temperature cannot generally be held as low as in the cold storage plant.

Handling apples. Early apples for cooking purposes may sometimes be picked green in order to reach an early market when prices are good; and it may be necessary to pick winter apples green in order to avoid autumn freezes or in order to get the entire orchard picked before there is serious dropping. However, it seems to be true with all varieties that the quality is best if the fruit is not picked until it is fully colored and will part rather easily from the stem. Powell and Fulton (1317) found that with some varieties, if not with all, fruit so picked will keep in better condition in storage than will fruit picked green. Fruit picked green scalds and wilts worse and does not generally keep longer than fruit picked after it is well colored.

With summer and autumn varieties transportation is in refrigerator cars. With autumn varieties and even with tender fleshed winter varieties that are to be held long in storage, transportation should be in refrigerator cars. Apples should be placed in cold storage as quickly as possible; particularly is this true in sections where the weather is warm at picking time. Thus, Powell and Fulton found, in the season of 1902 when the weather was warm during late September, that Rhode Island Greening apples stored within three days after picking were in better condition on March 1, 1903, than was fruit from the same trees on January 1st, if it had been delayed two weeks in getting to storage. This difference is, of course, explained by the fact that the fruit ripens so much more rapidly while at the higher temperature out of storage. With the best keeping varieties the loss from becoming too ripe or from rotting is less if the fruit is hastened to storage, but the use of iced cars is not so essential and may not be profitable. When the apples are shipped in winter it may be necessary to use uniced refrigerator cars. The insulation of such cars tends to reduce the danger of freezing; and sometimes it is found advisable to place oil heaters in the ice bunkers.

When cold storage warehouses first came into use, it was thought that temperatures below 35° or 36° F. might be injurious to tender varieties such as Fameuse. However, Powell and Fulton found that best results are generally obtained at a temperature of 31° to 32° F. And this is even more important for such tender fleshed varieties than for others. If apples that ripen very slowly are to be sold early in the winter it may be better to keep them at a higher temperature so they will ripen; but, for longest keeping, a temperature as low as possible, without danger of freezing, is best. Not all varieties have been studied as to the effect of such low temperature on quality, but no experience indicates that fruit of any variety of apple ripened at a temperature of 35° to 38° F. will have a measurably better flavor than when ripened at 30° to 32° F.; though some injuries that develop in storage seem to be worse at 32° F. than at 36° F. And fruit of some varieties, such as Grimes Golden, seems to be of better quality when ripened at a rather high temperature; perhaps 60° to 70° F. It seems probable that with such a variety, the better quality might be obtained if the fruit was stored at the lowest possible temperature, but was removed from storage while still hard and green and ripened at a temperature of about 65° F. Before discussing other storage practices, it seems well to discuss some of the injuries that develop in storage.

Freezing in storage and in transit. Wright and Taylor (1383) found ice formation beginning at 28.84° F. to 29.43° F. with Baldwin; 28.72° F. to 29.38° F. with Rome Beauty; 27.80° F. to 28.20° F. with Yellow Newtown; 27.79° F. to 28.69° F. with Jonathan, and 27.93° F. to 28.72° F. with Winesap. With Ben Davis, Delicious, Esopus, Grimes Golden, Stayman, and York Imperial generally ice formation begins at a temperature higher than with Winesap and lower than with Rome Beauty.

Carrick (963a) found with some common apple varieties the freezing temperatures and the killing temperatures shown in Table 78.

TABLE 78. THE FREEZING TEMPERATURE AND THE KILLING TEMPERATURE OF APPLE TISSUE

VARIETY AND LOCALITY WHERE GROWN	NO. OF DETERMINATIONS	TEMPERATURES AT WHICH ICE FORMATION BEGINS		TEMPERATURES CAUSING DEATH OF SOME TISSUE
		Range	Average	
Winesap, Wenatchee, Wash.	116	27.18° to 29.07° F.	28.35° F.	25.3° to 26.2° F.
Winesap, Yakima, Wash.	126	27.23° to 28.56° F.	27.79° F.	25.7° to 26.8° F.
Stayman, Idaho	112	27.18° to 28.69° F.	27.68° F.	25.5° to 26.6° F.
Yellow Newtown, Idaho	115	27.46° to 29.05° F.	28.15° F.	24.8° to 25.9° F.
Yellow Newtown, New York	108	27.21° to 29.39° F.	28.31° F.	24.2° to 25.9° F.
Ben Davis, New York	130	27.59° to 29.19° F.	28.47° F.	23.9° to 25.5° F.
Baldwin, New York	135	27.21° to 28.92° F.	28.24° F.	23.9° to 24.8° F.
Rome Beauty, New York	130	27.77° to 29.28° F.	28.38° F.	22.8° to 23.9° F.
Wagener, New York	122	28.11° to 30.16° F.	29.23° F.	26.1° to 27.1° F.
Jonathan, New York	104	27.63° to 29.21° F.	27.97° F.	25.5° to 26.2° F.
McIntosh, New York	136	27.32° to 29.32° F.	27.91° F.	26.1° to 27.1° F.
Tompkins King, New York	122	27.37° to 28.80° F.	28.08° F.	24.8° to 26.2° F.

While the killing temperatures are considerably lower than the temperatures maintained in commercial storage plants, initial ice formation is but little below 30° F.; and we have seen that Carrick found a very small amount of ice in the tissue to reduce the quality of fruit of some varieties. Greene (1254) says that Ben Davis and Jonathan frozen in storage did not seem to be injured by a temperature of 24° F., but were killed by a temperature of 20° F. With his apples that were not killed by the freezing he was apparently not looking for the small differences in flavor that Carrick noted. Since oxidation, and therefore breaking down of the tissue, is slower the lower the temperature, it is desirable to use the lowest temperature that will not injure the tissue. However, since there is some fluctuation in temperature in the storeroom, that near the pipes being the lowest, Carrick's observations suggest that there is little promise that a temperature lower than 30° to 32° F. may be practicable for apples. When apples become frozen in storage or during transportation there may be less injury if they are not handled while frozen.

Rotting. Injury from fungus diseases is fairly great in common storage and of some importance in cold storage. Brooks and Cooley (1202) have studied the temperature relations of apple-rot fungi. They found a number of organisms to continue growth at 32° F. after germination at higher temperatures. Initial germination stages seemed to be inhibited, more than was growth after germination, by a temperature of 32° F. This was true of the blue mold, *Penicillium expansum*, which they say causes eighty to ninety-five per cent of the rotting in storage. The results suggest that there is less injury from these fungi if fruit is hastened to storage after picking so that spore germination does not take place before the inhibiting temperature is reached. Carrick (1216) found blue mold to make little or no growth on Vinifera grapes at 27° F.

Apple scald. There are other injuries, physiological in nature, that seem to result from conditions brought about in storage. The most important of these is apple scald. This is a browning that occurs on the surface of apples in storage, becoming evident mainly after they are removed to higher temperatures. According to Brooks and Cooley (1203) it is usually confined to the five or six surface layers of cells that form the color bearing tissue, but in some cases it may extend through the skin of the apple into the larger isodiametric cells of the pulp, and is then sometimes called "deep scald." These workers made a careful study of the conditions that favor the development of this injury, and found it to develop readily in a moist chamber in loosely stoppered jars or under conditions where aeration was restricted. With a very high percentage of carbon dioxide at a temperature of 15° C., typical scald did not develop but rather a sort of rigor, perhaps a more general and severe injury. In moist chambers the rapidity of development of scald increased with a rise in temperature up to 20° C. However, they did not find scald becoming more severe with increase in humidity except under conditions where drops of water accumulated on the surface when there would seem to result locally poor aeration; and in open containers it did not develop at temperatures as high as 5° C. though it developed at 0° C. They think that the low temperature had a peculiar effect on the oxidation process in the skin.

Brooks, Cooley, and Fisher (1205, 1206) found that scald can be prevented by a movement of the air around the fruit. Thus, it is less serious on apples near the door of a refrigerator room where there is a movement of air when the door is opened. It is almost entirely prevented when the fruit is wrapped with a paper impregnated with fats or oils. They produced typical scald by exposing the apples to the vapor of ethyl acetate, amyl acetate or methyl butyrate. They conclude that scald is caused by esters of this nature given off by the apple through its katabolic processes and that these may be carried away by movement of the air or absorbed by fats and oils. The fact that there is little scald in common storage apparently is due partly to the greater movement of the air. These workers (1208) divide the life of the apple after it is picked into four periods with reference to scald. The first, during which scald-producing agencies are most active, is in the six to eight weeks following the picking of the fruit. During this period preventive measures are most useful. The second period comprises the five to six weeks after the end of the first. During this period preventive measures are of little or no avail; but, if the fruit is removed during or at the end of the period, it does not scald even upon being warmed. The third period extends from the end of the second period to the end of the storage period. During this time the apples while in the cold rooms are green and appear normal; but the skin becomes brown on exposure to warm air. The fourth is the period after the apple is removed from storage and exposed to warm air. It is during this period that the skin turns brown and the fruit unprotected by a living skin is often rapidly injured by the rot-causing organisms. According to these workers a complete change of air in the storeroom is not necessary to prevent scald, but only a movement of the air around the fruit so that the injurious substances will be carried away from the surface of the fruit. Fanning in the closed room reduced the amount of scald, though it is not clear how it could have that effect with tightly barreled apples. If scald was worse in a humid room it was only because drops of water accumulated on the fruit and the injurious substances became concentrated. Less scald developed in ventilated than in tightly closed packages provided the storage room was occasionally ventilated; but there was little benefit from ventilated packages in an unventilated storeroom.

Scald is generally worse on fruit picked green and seldom develops on the part of the apple that is well colored. These workers found it worse on fruit surfaces just changing from green to yellow than on surfaces that were of a leaf green, or on those that had completely changed to yellow. However, the initial development was probably while the fruit was of a leaf green.

Internal browning. With Yellow Newtown apples and to some extent with other varieties grown in the Pajaro Valley of California there is a browning in the tissue that, in some respects, resembles apple scald. It was first described by Powell (1316) as internal browning and since that time has been studied by his successors in the cold storage investigations in the United States Department of Agriculture. Recently, the results of rather exhaustive studies of the injury have been reported by Ballard, Magness, and Hawkins (1193), Winkler (1381a) and Overholser, Winkler, and Jacobs (1309). Winkler says that, with apples grown in that valley and stored at 30° to 32° F. as soon as they are harvested, browning generally becomes noticeable late in December; the disease appearing first as more or less elongated areas radiating outward from the primary vascular bundles. According to Ballard *et al.*, there is a tendency for the first development to be around the core particularly near the stem end in the angle between two adjacent cavities, though, rarely, the first browning may be in the outer flesh. According to Winkler, the large cells adjacent to the bundles are generally the first to show browning, followed by the smaller cells bordering on the bundles; the bundles themselves becoming brown only in the advanced stages. In the later stages all of the pulp may be brown resembling that of apples that have become overripe and broken down.

Winkler found that, with apples grown and stored under conditions favorable for the developing of browning, toward the center of the apple there is a reduction in permeability (as indicated by electrical conductivity) preceding and during the development of the browned areas. Drops of weak solutions of essential oils such as amyl acetate, amyl valerate, and acetaldehyde on the tissue would cause such reduction in permeability and would cause browning. We have seen that Power and Chestnut found that some of these substances are being produced continuously in the apples in quantities large enough to be detected; and that Brooks *et al.* think that apple scald may be caused by the accumulation of such substances on the fruit. Of course, the fact that weak solutions of a substance would cause increased permeability and browning is not necessarily proof that in storage browning is caused by the same substance. Probably most toxic substances would have such an effect. However, Winkler found the development of the injury to be favored or inhibited in many ways as with apple scald. Thus the injury developed more rapidly at 30° to 32° F. than at higher temperatures. The amount of injury to develop seemed to be reduced by ventilation and by oil paper wrappers; though the amount of reduction was not as great as with scald. Since removing such substances from the surface could influence the amount deep in the tissue only by reducing the concentration at the surface, and thus causing a movement in that direction, the effect of ventilation and of oils would naturally be slower with internal browning than with scald.

The workers in storage investigations in the United States Department of Agriculture early found that apples stored at temperatures of 35° F. or a little higher show much less browning than do apples stored at 32° F.; and, as a result, since 1910 Yellow Newtown apples grown in the Pajaro Valley have generally been stored at 36° F. Since the variety keeps exceedingly well it is possible to hold it at such a temperature and yet have it remain marketable until late in the winter apple market season. A considerable amount of browning may develop, however, at 36° F. and some at 40° F. Winkler never found any at a temperature as high as 47° F. Ballard *et al.* found the amount of browning very greatly increased ten days after removal from storage.

While injury from internal browning can be reduced or prevented by storage practices such as ventilation, use of gas-absorbing wrappers, or maintaining a storage temperature well above that normally used, the susceptibility of the apple to internal browning in storage is influenced by orchard conditions. Winkler, and Overholser, Winkler, and Jacobs found the summer temperature, in which the apples are grown, greatly to influence susceptibility to browning in storage. Other varieties than Yellow Newtown grown in the low temperature of the Pajaro Valley were susceptible to some extent. Yellow Newtown from other sections stored with those from this valley were much less susceptible, and were susceptible approximately in inverse proportion to the summer temperature where grown. In the Pajaro Valley when the temperature of the apples was raised about 7° F. during the day through the summer by covering them with black bags, their susceptibility was reduced; while when the temperature was lowered about 6.3° F. by shading the entire tree susceptibility was increased. Ballard *et al.* found that ringing branches in June when the fruit was about three fourths of an inch in diameter and thinning the fruit until none were closer to each other than five inches, caused the fruit when mature to be much more susceptible to browning than was the fruit on normal branches; while removing half of the leaves from a branch in June and leaving all the fruit reduced the susceptibility to internal browning of the mature fruit. The fruit on the ringed, thinned branches was very large and was becoming yellow when picked; while that on the partly defoliated branches was small and green when picked. Since the fruit on the ringed, thinned branch was the largest and also the most mature when harvested and that on the partly defoliated branches the smallest and least mature when harvested, it is hardly certain whether the ringing and defoliating caused the increased and the decreased susceptibility to browning by influencing size or by influencing maturity. For the workers mentioned found that fruit on a tree bearing a full crop of apples of medium size is less susceptible than is the large fruit on a tree bearing a light crop. Further Winkler, and Overholser, Winkler, and Jacobs found that fruit picked in late September and early October when it was hard green was less susceptible than was fruit picked after the yellow color had begun to show. The condition of the tree in a given year influenced the susceptibility of the fruit borne; very vigorous or very weak trees bearing more susceptible fruit than was borne by trees of medium vigor. Orchard management that tends to cause the development of uniformly heavy crops of fruit of medium size seems desirable for the development of fruit with the least susceptibility to this injury in storage.

Jonathan spot. This is a disease resembling apple scald and has been studied by Brooks and his associates. They describe it as superficial black or brown spots in the apple, especially common on the Jonathan variety. In early stages, only the superficial color bearing cells are involved, and the spots are seldom more than 2 mm. in diameter. However, spots may be as large as 3 to 5 mm., become slightly sunken and spread into the tissue. Both Jonathan spot and scald injury may serve as points of infection for storage rots. Brooks and Fisher (1210) seemed to find Jonathan spot a little worse on apples picked early than on those picked when fully ripe; the reverse of the experience of Plagge and Maney (1311). Hastening the fruit to storage after picking and avoiding exposure to high temperature after removal from storage seemed to be fairly promising methods of reducing the amount of injury from this disease.

Brown heart. Kidd and West (1272a) apply the term "brown heart" to the injury in the tissue caused by excess carbon dioxide in the atmosphere surrounding the fruit. This injury, when but slight, may appear as small isolated patches of dead tissue in the interior of the fruit. It may appear first in the pith or in the cortex or in both. If the apple is removed to a storage chamber in which the amount of carbon dioxide is not excessive, the injured areas do not grow. The killed tissue eventually becomes dry and brown, due to the absorption of the water by the living tissue around it. If the concentration of carbon dioxide is very high or if the harmful conditions are prolonged a large part of the tissues of the apple may be killed. Some of the results of Kidd and West suggest that a very brief exposure to high concentration of carbon dioxide may cause the injury. With most of their studies, when the concentration of carbon dioxide was high, that of oxygen was low; and so it was not clear whether the injury was due to the presence of carbon dioxide or to the reduced supply of oxygen. However, it was found that when the carbon-dioxide concentration was high the injury could not be prevented by maintaining artificially a high concentration of oxygen also; a suggestion that the injury was due to the presence of the carbon dioxide. The danger limit was found to vary for different varieties and for different fruits of the same variety, the lowest concentration of carbon dioxide in the storage atmosphere that caused injury being 13.6 per cent; and usually concentrations below twenty per cent were not injurious. Ripe fruit was markedly more resistant to the injury than was immature fruit. Low temperature increased the susceptibility of the fruit to injury from a given concentration of carbon dioxide. Yet they were able to cause a similar injury by keeping the fruit at high temperature (113° F.) without high concentration of carbon dioxide in the atmosphere surrounding the fruit. This, they think, may be due to the high concentration of carbon dioxide in the intercellular spaces that results when the fruit is held at high temperature, their own findings in this regard agreeing with those of Magness (1283).

They found much of this injury with apples carried in the holds of ships, particularly in the holds into which the fruit was placed without being precooled. In such holds, the content of carbon dioxide was sometimes as high as 38.5 per cent; and that of oxygen less than one per cent. Precooling the fruit before placing it in the holds greatly reduced the amount of "brown heart" or prevented its appearance altogether. This was, of course, due to the fact that respiration of the fruit was much less rapid at the lower temperatures. They show that only a small amount of ventilation is necessary in order to prevent injurious concentrations of carbon dioxide in the holds. Forced circulation of the atmosphere within a hold generally caused the entrance of enough air from the outside to prevent injurious concentrations of carbon dioxide. They think that it may be possible so to regulate the ventilation of the holds that the concentration of carbon dioxide will be kept too low to cause injury to the fruit but high enough to delay its ripening.

Bitter pit and water core. There is another type of injury that often becomes evident in storage, though it has its beginning, or its cause at least, in the orchard. It is called "bitter pit," "Baldwin spot," or "stippen." The injury appears on the apple either at picking or in storage; at first as minute, water-soaked spots resembling bruises. The color whether red or green is deeper than that of the surrounding area. Later the spots become pits or sunken areas; and eventually there may be numerous brown spots in the flesh.

According to Brooks and Fisher (1210), the pits are usually associated with the terminal branches of the vascular bundles and there is often a browning of the vascular tissue deeper in the fruit, showing as internal brown spots. Either the surface pitting or the brown spots may be present without the other. Affected tissue often has a bitter flavor. These workers list Baldwin, Northern Spy, Grimes Golden, Jonathan, and Yellow Bellflower as especially susceptible. Tompkins King and Fall Pippin are also very susceptible. McAlpine (1289) has given much attention to this injury and concludes that it is associated with the failure of the vascular system to develop properly. In his experience cultural practices that favored excessive growth of the fruit late in the season encouraged the development of this injury. It was worse on young trees; and excessive pruning resulted in more injury. So did excessive watering late in the season. McAlpine thinks that under such conditions the vascular system fails to keep pace in development with the other tissue. Brooks and Fisher (1210) found that heavy irrigation late in the season greatly increased the amount of injury and heavy irrigation following medium irrigation increased it even more. With light irrigation throughout the season there was less of the disease, but the least was found on plots receiving heavy irrigation early in the season and light irrigation later. Large apples show more injury than small ones, but apples of the same size were injured worse on trees receiving heavy late irrigation than on trees not so irrigated.

Heinicke (1263) divides this disease into two classes, that which becomes apparent before the fruit is picked and that which does not show until after harvest. He found much less of the first class on central fruits in a cluster and on fruits with many good seeds than on lateral fruits in a cluster or on fruits with few seeds. However, with the second class of injury there was more on the fruits with many seeds. Due to the effacement of markings from some of the central fruits of the clusters, they could not be separated from the others, and so he could not learn whether or not more of this second form developed on the central fruit. Fruit at the base of branches or on weak branches showed more of the first form. Due to the accident mentioned, it was not learned whether such fruits developed more or less of the second form. He thinks that the injury of the first class is associated with lack of water or nutrients since it develops first on fruit in positions where such deficiency is most liable to prevail. There was much water core in the orchard when the fruits were studied and it seems probable that the presence of water core may have delayed the appearance of the bitter pit. Conditions unfavorable to the obtaining of water would reduce the amount of the water core and might thus prevent the obscuring of bitter-pit markings.

Water core appears as translucent, glassy, water-soaked areas in the fruit. Sometimes there may be water core in the flesh around the larger vascular bundles when the glassiness does not show in the skin, or shows but slightly. Water-cored fruit is heavier than other fruit and the flesh is more rigid. At harvesting time the cells do not seem to be dead. In fact, with the milder cases, the water seems to be absorbed by the tissue or lost from the surface in storage at temperatures well above 32° F.; and some warehouse managers place fruit containing much water core in rooms at such higher temperatures expecting much of the injury to disappear. However, with injured areas of considerable size and severity, the condition continues until the tissue breaks down. This breaking down occurs generally considerably earlier in water-cored areas than in uninjured areas.

Water core seems almost certainly to be caused by an excessive water supply to the fruit late in the growing season. Brooks *et al.* (1207) say that it is prevalent in sections where the water supply is abundant and the sunshine intense. On the other hand, Frank (1242) says that reduced transpiration seems to encourage its development. It is certainly very serious in sections such as that in which Ithaca, New York, is located, where, although the rainfall is not great, the amount of cloudiness is such that transpiration is very low during the later weeks of the growing season. In that section there is much cloudiness during periods of high barometric pressure when there is little or no rainfall; and water core is much more serious than in any other section that I have ever known. It may be serious in years when there is much cloudiness during the ripening season, even though the soil is rather dry. It seems probable that the cause of water core is an excessive water supply to the maturing fruit; whether that excess is caused by an exceptional soil water supply or by a greatly reduced transpiration. To me, it does not seem impossible that, with such reduced transpiration, metabolic water may be of importance in causing water core.

At Ithaca, New York, many varieties such as Fall Pippin, Tompkins King, Baldwin, Gravenstein, Wagener, Twenty Ounce, and others seem very susceptible; though Wealthy, McIntosh, Fameuse, Jonathan, Rome Beauty and Red Canada seldom show such injury.

The conditions that favor the development of water core seem in some cases at least to favor also the development of bitter pit; though the stage of development when a large water supply to the fruit is most influential may not be exactly the same for the two forms of injury. Bitter pit is very serious at Ithaca, New York, when the water supply is abundant and when there is much cloudiness in August and September. In exceptionally dry years when maturity is early it is much less serious. This seems to be in agreement with the results of Brooks *et al.* with late irrigation. Overholser, in unpublished work, found with Gravenstein apples from the Sebastopol district of California that the earlier picked fruits, particularly those of the larger sizes, which were also the earlier maturing fruits, showed much more bitter pit in storage than did fruit of later pickings. In that district the dense fogs tend to cease each year from two to three weeks before the earlier picking begins. It may be that the fruit of earlier pickings reached a stage to be injured by an excess water supply before the fogs ceased and transpiration increased. He observed also that in coastal regions of California, such as the San Francisco Bay region, summer apples such as White Astrachan, Early Harvest, Sweet June, and Red Astrachan develop more bitter pit than do varieties that ripen later. The foggy season, when transpiration would be low, is in midsummer when these varieties are ripening.

There seems to be no certain means of avoiding bitter pit or water core in sections where the rainfall is excessive or transpiration very low. However, under some conditions, keeping the water supply to the tree abundant early in the season so that there will be a large leaf surface, and, if irrigation is practiced, watering moderately late in the season seem to cause some reduction in the amount of injury. Hastening the fruit to storage and holding it at a uniformly low temperature will delay the enlargement of the injured areas, according to Brooks *et al.* (1207).

Drought spot and cork. Mix (488) and Brooks and Fisher (1210) have described as drought spot an injury that, at first, shows as large irregular water-soaked spots, often with a reddish margin. There is dead tissue just beneath the skin and occasionally brown streaks follow the vascular bundles deeper into the tissue. The skin is not dead; and so, as the apple grows, the injury appears merely as sunken areas. It seems to be caused by sudden drought and has been produced experimentally by withholding water in irrigation regions. Allen (927) found in the Hood River apple district that a pitting of the fruit, probably drought spot, was common on trees whose roots were mainly near the surface of soils low in organic matter, compacted by shallow tillage, and holding an inadequate water supply during the growing season. The injured areas do not enlarge in storage.

Cork, described by Mix and Brooks *et al.*, also seems to be caused by drought, but the dead areas are located in the pulp of the apple, often quite deep. There may be no external marking to indicate that the disease is in the apple. Both these forms of injury develop on the tree and are caused by some unfavorable condition in the orchard.

Wilting. One rather serious injury that may develop in storage is wilting. Powell and Fulton (1317) have shown that there is much more wilting with fruit picked green than with fruit that reaches full color development before it is picked and has a thicker waxy protection against water loss. The amount of wilting may be influenced greatly, also, by the method of packing and handling in storage, a low uniform temperature being desirable. Closed packages reduce the amount of wilting but may increase scald injury.

Storage practices. With some of these injuries in mind, as well as the natural breaking of the fruit after its becoming ripe, we may study the effect of some handling practices on the keeping in storage.

Powell and Fulton (1317) found that apples remain sound in storage longer if they are wrapped with paper. It would be expected that since the wrapper prevents bruising and keeps rotting apples from contact with others it would reduce the spread of rot-causing fungi. Wrapping would also be expected to reduce the loss of water from the fruit. In addition to these benefits, however, wrapping seems to retard ripening and to keep the fruit longer in prime condition. Results obtained by Powell and Fulton with apples in bushel baskets are shown in Table 79.

TABLE 79. AMOUNT OF DECAYED FRUIT APRIL 29, 1903, IN BUSHEL PACKAGES

Variety	Newspaper wrapped (per cent)	Unwrapped (per cent)	Variety	Newspaper wrapped (per cent)	Unwrapped (per cent)
Baker........	3.7	27.2	Northern Spy..	5.6	52.0
Dickenson	6.4	43.0	Wagener......	38.0	63.0
McIntosh.....	7.7	15.0	Wealthy	42.0	60.0
McIntosh (second lot).....	19.7	32.0			

Wrapping rather markedly delayed the breaking down of these fruits. The wrapper, by preventing the movement of air, might be expected to increase the amount of scalding. However, Powell and Fulton found no influence of wrapping upon scald; and Brooks, Cooley, and Fisher (1205) found that common paper wrappers have no influence, while paper wrappers treated with oils will prevent scald. It should not be assumed that, because wrapping delays the normal breaking down of fruit, reduces wilting, and inhibits the spread of rot fungi, it must necessarily be a profitable practice in all cases. Much of the annual apple crop is consumed before there will be an appreciable amount of loss from wilting, breaking down, or rots. In fact, it is only with the better grades of fruit that wrapping is possible, economically; and it has not yet come to be practiced in the northeastern part of the United States, even with a variety such as McIntosh, having very tender flesh and very high quality.

The size of the package is of some importance. Thus, the larger the package the more slowly the fruit cools in the center. Then, when the fruit is very ripe, the weight of the larger mass on the lower fruits in the package may be injurious. This can be of importance, however, only with fruit that ripens very rapidly or fruit that is to be kept until it is very ripe. Only a small percentage of the apple crop falls in either of these classes.

The nature of the package also must be considered. Thus, there is less scald on apples in open or ventilated packages; but there is more wilting; and so the ventilated package seems to be of little promise in practice with apples.

The condition of the fruit when it reaches storage is of great importance. The bad effect of not getting the fruit quickly into storage after it has been picked has been discussed. It is evident that if the fruit is bruised or the skin broken, there may be browning at that point and also that such injury may furnish means of entrance for various storage rots.

Cultural methods and conditions have their influence. Powell and Fulton (1317) found that Tompkins King, Hubbardston, and Sutton Beauty apples from rank-growing young trees ripen more rapidly and break down more quickly in storage than do those from more slowly growing old trees. With Rhode Island Greening, scald was worse on fruit from young trees. However, with the varieties Mann and Baldwin grown in sandy soil fruit became overripe sooner than did fruit of the same varieties from clay soils. Considering wilt, scald, and loss of quality from becoming overripe, Powell and Fulton found that, with most varieties of apples, the fruit keeps best if it is not harvested until it has reached full size and, if a red variety, is well colored.

The length of the possible storage season for all of the many cultivated varieties of apples is not a subject belonging to this discussion. But Table 80 gives an indication of the losses to be expected with common varieties under average storage conditions as storage practice has been brought about by Powell and others. The table was compiled by

Mr. E. D. Vosbury from the answers to the question, "What is your estimate as to the average loss from all causes for the following varieties received in good condition in October?"

TABLE 80. LOSS OF APPLES IN STORAGE

VARIETY	PER CENT OF LOSS JANUARY 1ST	PER CENT OF LOSS MARCH 1ST	PER CENT OF LOSS MAY 1ST
Baldwin	0 to 1	1 to 2	2 to 3
Rhode Island Greening	1	3 to 4	5 to ..
Ben Davis	0 to 1	1	2 to 3
Tompkins King	1 to 2	3 to 5	10 to ...
Northern Spy	1	2 to 5	8 to ....

.. Few held after April 1st.
... Few held after February 15th.
.... Varies greatly, from two to thirty per cent, after April 1st.

Table 80 gives no indication as to the amount of loss after the fruit has left storage. It suggests, however, that with the common varieties, under average conditions of care, the losses are not large until after most of the apples have been moved.

From what has been said it is evident that after fruit is removed from cold storage to the temperature of a retail store it may deteriorate as much or more in three or four days as it would in a month in storage. Of course, the higher the temperature to which they are removed the more rapid the deterioration will be. Powell and Fulton found that where apples have incipient scald when removed from storage the visible scald will appear on the apple much more rapidly when removed to a high temperature; Table 81 shows the results of removing apples from the same barrel in cold storage to different temperatures.

In another table they record nearly as striking results concerning the effect of the temperature to which the fruit is removed from storage on the breaking down or rotting of the fruit. For example, of Baldwin apples removed from storage to rooms at different temperatures on January 29th and examined February 20th, none of those held at 44° F.; four per cent of those held at 48° F.; twenty-three per cent of those held at 61° F.; and twenty-eight per cent of those held at 67° F. had decayed.

If the apples have not gone far in the ripening process when removed from storage, exposure to a high temperature will do less harm. In fact, it is possible that with some varieties it might encourage the development of a better flavor than would be developed at a low temperature. This

TABLE 81. SCALD DEVELOPED IN DIFFERENT TEMPERATURES WHEN APPLES WERE REMOVED FROM STORAGE

VARIETY	DATE REMOVED FROM STORAGE, 1903	DATE INSPECTED 1903	PER CENT OF SCALD			
			44° F.	48° F.	61° F.	67° F.
Baldwin..........	Jan. 29	Jan. 29	0	0	0	0
"	"	Feb. 3	0	6	21	22
"	"	Feb. 4	4	11	21	37
"	"	Feb. 6	4	25	40	63
"	"	Feb. 7	4	25	41	63

question needs further study. It is almost certain, however, that, late in the storage season, there is much loss of fruit caused by unnecessary exposure to high temperature in retail stores and in homes. Perhaps one of the most important precautions in handling apples is to get them on the market before they are overripe. This is generally handled well by market agencies. It is more liable to be overlooked by isolated growers with common storage houses. Generally, fruit of the longer keeping varieties such as Baldwin from common storages in north latitudes of 39° to 45° F. should nearly all be moved by March 1st. Earlier maturing varieties and others in lower latitudes must be moved from common storage earlier. Since the temperature in common storage depends to some extent upon weather conditions, it is necessary to move the fruit earlier in some years than in others. While common storage houses make possible the storing of fruit more cheaply, fruit so held is often a disturbing feature in the market because weather conditions sometimes make it necessary to move a large percentage of it within a short period of time.

Briefly to summarize, apples will keep in prime condition longest if, except in sections where the weather late in the season is so cool that the fruit does not develop normally, the fruit is not picked until it is fully colored; if it is wrapped with paper; if it is packed firmly but without bruising in small packages such as bushel boxes; and if, within a few hours after picking, it is placed in cold storage at a temperature of 30° to 32° F. However, the losses in storage with the common market varieties are not generally great enough to justify the expense of some of these practices such as wrapping and packing in boxes. Even delaying the picking of the fruit until it is in just the right stage of ripeness may in some sections involve more risk of loss from winds than is profitable under average orchard conditions. And getting the fruit to storage within a few hours or a day or two after picking, though a practice generally to be strongly encouraged, may at times involve greater expense or inconvenience than the benefits warrant, in so far as the firmer fleshed, better keeping apples that are not suited for fancy markets are concerned.

Handling pears. Wright and Taylor (1383) found ice formation to begin in the tissue of hard ripe Bartlett pears at 28.06° F. to 28.70° F., and in that of soft ripe ones at 27.20° F. to 28.00° F. Mr. F. DeVilliers in unpublished work, found the temperature of initial ice formation to be a little lower with Beurré d'Anjou, Beurré Bosc, Kieffer, Seckel, and Winter Nelis than with Bartlett, that of Kieffer being next to that of Bartlett, all the fruit being grown at Ithaca, New York.

It was formerly taught that the pear reaches better quality (or certainly as good quality) if it is picked green. It was thought to contain fewer of the characteristic grit cells when so picked. It is probably true that fruits of the pear will come nearer than will most other fruits to reaching the best quality, in spite of being picked so green that they have not nearly reached full size. However, Lewis, Magness, and Cate (1276) never found the quality of fruit of varieties grown in Oregon improved by early picking. With Bartlett, and especially with Beurré Clairgeau and Beurré d'Anjou, the quality was much better when the fruit was not picked until nearly ripe. With Howell there was less difference, while with Beurré Bosc the quality depended more upon the temperature and humidity at which ripening proceeded than upon the picking time, though the quality of the later picking was much the better unless those picked early went through a ripening process in a high temperature room. They found a considerable increase in the size and weight of fruit as the picking season advanced. In other words, there may be a considerable loss in yield when the fruit is picked while very immature.

Powell and Fulton (1312) say that the Kieffer pear may be picked from the time it is two thirds of full size until it is of full size and it will keep in storage until after Christmas, in fact until March; the fruits picked early being of the better quality because the flesh is not so full of grit cells. It is probable that other hybrids with the oriental pear may be thus benefited by being picked green. Lewis and his associates and Stubenrauch and Ramsey (1354) found that Bartlett pears picked very green will not keep as long in cold storage as when picked a little riper, though the fruit picked latest did not hold up as well as that picked midway between the earliest, in practice on the Pacific Coast, and the latest.

However, in common storage at temperatures of 66° to 73° F. fruit picked green kept the longest. Magness (1282, 1284) found that at 40° F., about the lowest temperature that can be maintained in a refrigerator car, Bartlett pears that mature on the tree reach prime condition for eating sooner than do those picked green; but they stay in prime condition longer. At refrigerator-car temperatures, Pacific Coast Bartlett pears picked green, therefore, reach eastern markets in a greener condition than does fruit picked when more nearly mature; and the markets require that the fruit appear green when it is sold to retailers. It is therefore probably not safe, with the present market requirements, to delay picking until the fruit has reached a stage of maturity such that it will develop the best quality.

Lewis, Murneek, and Cate (1277) and Murneek (1297) describe an apparatus for determining the maturity of pears by means of pressure tests, the force required to press a blunt, rounded plunger one half inch in diameter a given depth, automatically gauged, into the side of the fruit at the point of its greatest diameter. This pressure becomes less throughout the ripening season. In other words the pear becomes softer. Of course, it is necessary to use a considerable number of pears that seem to be typical of those in the orchard at the time. They seemed to find the test a rather accurate measure of the maturity of the pear. Bartlett pears should not be picked before the pressure is as low as thirty-five pounds; and, for shipping, should be picked before the pressure is lower than twenty-five pounds. Fruit for drying or canning may be left on the tree until the pressure is even less than 25 pounds. Beurré Bosc may be left until the pressure is 24 to 20 pounds; Howell until it is 29.5 to 24 pounds. The pressure test seemed to be less accurate as a measure of ripeness with Beurré Bosc than with Bartlett. Later, Murneek (1298) reported a histological study of the maturing Bartlett pear. From August 20th to September 17th in Oregon there was a reduction in resistance to pressure of about one half pound for each twenty-four hours. He suggests that this is probably due, in considerable part, to chemical changes in the tissue; but he found that during that time the cells of the cortex had increased in size 93.7 per cent and the walls had decreased in thickness 14.8 per cent; and the cells of the lower portion of the subepidermis increased in size 65.6 per cent, while those of the first layer beneath the epidermis increased 39.3 per cent. The epidermal cells increased in size 14 per cent and the cuticle covering them decreased in thickness 19 per cent. These changes would certainly result in some reduction in resistance to pressure; but it is probable that the softening is due more largely to chemical changes in the tissue. For the softening is rather rapid after the fruit has been harvested and cell enlargement has stopped.

Stubenrauch and Ramsey (1354) found that picking the fruit about two weeks later than it is commonly picked, placing it in storage or in iced refrigerator cars as soon as possible after picking (two days delay caused marked deterioration), makes it possible to store Bartlett pears, from Pacific Coast sections, four or five weeks in addition to shipping them across the continent. Thus, counting the two weeks delay in picking, the season of Bartlett pears from that section could be extended six or seven weeks. Magness (1284) found that with proper picking and handling, cooling the fruit very soon after it is picked and storing at a temperature not above 30° F., the Bartlett pear grown in some sections of California may be stored for two to three months and taken out in good condition. He found that even when the fruit is to be used long before the end of the possible storage limit a fruit of better quality is obtained if it is held at 30° F. until a short time before it is to be used and then is ripened at rather high temperature. The pears stored at 30° F. and ripened at a temperature as high as 70° F. have more sugar and a better quality than when ripened in a storage temperature of 35° to 40° F. Magness emphasizes the fact that Bartlett pears, picked as green as many growers pick them, never develop the best possible quality. This is true also of pears to be canned. Most of the canned fruit of low quality was picked green. However, if the fruit is all left on the trees until the prime stage of ripeness is reached, the canning factories will either have more fruit than they can handle during a short period or they must have storage facilities available. Some have thought that fruit held at a temperature of 30° or 32° F. will discolor in the can. However, Magness found that a canned product of excellent quality was obtained when Bartlett pears were removed December 29th, after nearly five months in storage and canned January 4th. The pears, however, were too ripe for the greatest economy in preparation; and he does not think that Bartlett pears for canning should be held more than two months in storage even at 30° to 32° F.

Magness says that climatic conditions where the pears are grown have much to do with the carrying quality of equally mature fruits. Bartlett pears grown in the Antelope Valley of California, where the summer temperature is very high, have a widely known reputation for shipping quality. From such a section the fruit tends to be close grained in texture, to be rather firm when fully ripe, and to ripen very evenly. On the other hand, fruit of the Bartlett from some cooler sections tends to ripen more rapidly, to be coarse grained, and to become overripe and discolored in the core region, when at the surface it appears entirely sound. In Table 82 are shown the observations of Magness (1284) concerning the average maximum and minimum temperature of some of the Pacific Coast pear-growing sections and the nature of the fruit produced. Of course, it is probable that with a number of other varieties than Bartlett low summer temperature would not be so injurious to shipping quality and might be actually beneficial as to flavor. Magness found that even the fruit from the sections with the coolest summers, after being held as much as one month at 30° to 31° F., will ripen normally and make an excellent canned product. However, due to the fact that fruit from such a section breaks down around the core while it is still sound at the surface, canners have sometimes been deceived as to its condition and held it too long.

Lewis, Murneek, and Cate (1277) and Murneek (1297) found very interesting results with Beurré Bosc. This variety will not reach its normal high quality when ripened at low temperature. They found, however, that even though it is picked rather green it will acquire its characteristic fine quality if ripened in a warm humid room. In a dry warm room it wilts badly and does not ripen properly. They found the quality much improved if the fruit was held for ten to fifteen days in common storage at a temperature of 45° to 70° F. with sixty to seventy per cent humidity, and then placed in cold storage. The quality was strikingly better when the delay was fourteen days instead of seven. By following these precautions, and using the best storage practice, they were able to keep Beurré Bosc pears grown in Oregon three months, or for the Christmas trade. Their best results were obtained by the following plan. Delay ten to fifteen days at temperatures and humidity mentioned above; car temperature, 50° to 62° F. and humidity sixty to seventy-five per cent, twelve to fifteen days; then cold storage. They found, however, that there was less need for this preliminary ripening at high temperature the more mature the fruit was when it was picked. Overholser and Latimer (1307) found this variety to develop very good to excellent quality in storage at 32° F. if picking was delayed until about two weeks later than the normal commercial harvest period in California. Fruit picked at such a stage of ripeness kept better at 32° F. than at 36° F., but fruit picked green kept as well at 36° F. as at 32° F.

Overholser and Latimer studied the behavior in storage of fruit of a large number of varieties of pears grown in California, the fruit being harvested at different dates. With most varieties, it was found that when the fruit was picked at the proper stage of maturity it kept better at 30° to 32° F. than at a higher temperature; but if the fruit was picked too

TABLE 82. RELATION BETWEEN THE SHIPPING QUALITY OF BARTLETT PEARS FROM DIFFERENT DISTRICTS AND THE TEMPERATURE CONDITIONS UNDER WHICH THEY ARE GROWN

DISTRICT AND STATION	JUNE AVERAGE		JULY AVERAGE		AUGUST AVERAGE		SEPTEMBER AVERAGE		
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
Antelope Valley, California: [a]									Fruit of very highest keeping and shipping quality.
Upper Sacramento Valley:									
Chico	89.3	55.0	98.9	60.2	97.4	58.3			Fruit of excellent keeping and carrying quality.
Red Bluff	87.8	61.6	94.7	66.3	95.1	65.1			
Marysville	87.9	58.0	95.8	60.8	94.6	59.5			
Sierra Nevada foothills:									
Rocklin	86.0	52.7	94.7	58.8	94.2	57.3			Fruit ripens evenly and is of firm texture.
Auburn	85.1	55.0	91.7	61.1	91.8	60.3			
Lower Sacramento Valley: [b]									
Sacramento	82.3	56.2	88.8	58.2	88.8	57.7			Occasionally fruit becomes overripe in transit east, particularly from the lower and cooler portions of this region.
Lake County, California:									
Upper Lake	83.5	50.0	93.2	54.4	92.9	52.6			Fruit holds up well and ripens evenly.
Rogue River Valley, Oregon: [c]									
Ashland	76.3	47.0	86.2	51.9	85.4	51.5			Considerable difficulty during certain seasons from fruit breaking down in transit.

[a] The temperature record is not available, but the summer range is the highest of any place listed.
[b] The main pear district is somewhat cooler than Sacramento. Records are not available.
[c] The main pear district is at a much lower elevation and is warmer than the above records show.

TABLE 82. RELATION BETWEEN THE SHIPPING QUALITY OF BARTLETT PEARS FROM DIFFERENT DISTRICTS AND THE TEMPERATURE CONDITIONS UNDER WHICH THEY ARE GROWN (*continued*)

DISTRICT AND STATION	JUNE AVERAGE		JULY AVERAGE		AUGUST AVERAGE		SEPTEMBER AVERAGE		
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
Yakima, Washington:									
Moxie	80.9	48.0	88.9	53.1	87.4	51.1	77.3	42.4	Great difficulty in shipping; careful precooling necessary.
Wenatchee, Washington:									
Wenatchee	74.9	49.0	83.7	55.8	81.0	54.6	71.4	47.6	Tendency to break down at core.
Santa Clara Valley, California:									
San José	76.9	48.7	80.9	52.0	79.9	51.3			Fresh eastern shipments practically abandoned because of breaking down in transit.
Santa Clara	77.0	46.5	82.5	50.6	81.5	49.6			
Sonoma County, California:									
Santa Rosa	77.9	45.8	82.0	49.1	82.1	47.1			About the same as Santa Clara Bartletts.
Willamette Valley, Oregon:									
Salem	72.1	49.7	79.6	53.3	80.1	53.1			Little attempt made to ship to eastern markets; Canneries take total crops.
California Coast district:									
Oakland	72.7	52.7	73.0	53.8	70.2	54.3			Fruits very poor keeping; marked tendency to break down inside; Santa Cruz County(Watsonville)Bartlett especially bad.
Watsonville	68.0	47.7	68.1	47.0	68.2	45.5			

green, it generally kept better and reached better quality if held at 36° F. than if held at 32° F. This was particularly true of Beurré Bosc. With Beurré Bosc, Doyenne du Comice, and Beurré Hardy, when picked during the height of the commercial harvest period and stored at 32° F., the maximum storage period was 141 days, while with fruit of the same varieties picked two weeks later it was 158 days. The latter developed high quality while in storage with no ripening period at a higher temperature, while the former developed only medium to rather low quality. Fruit picked a little too ripe went down rather quickly. Of course, even with fruit picked at the best stage of maturity for keeping, there would not be such a long storage period if it had to be shipped long distances in refrigerator cars and handled in wholesale and retail markets. These varieties kept only 37 days at 45° F. and in the retail store, the temperature would be considerably above 45° F.

Magness (1284) says that Bartlett pears held in storage often come out with the skin in a blacked condition, somewhat resembling scald. Less of this injury developed on fruit held at 28° to 30° F. than on fruit held at higher temperatures. Overholser and Latimer found some varieties to develop scald at 30°, 32°, 36°, and 45° F., though, generally at 45° F., the fruit decayed before scald developed. Pears held at 36° F., scalded worse than those held at 30° to 32° F. This is not in agreement with the results that have generally been obtained with apple scald. However, Carrick (1216) found scald worse with Wagener apple when stored at 36° than at 32° F., and worse at 32° than at 30° F. Overholser and Latimer found that fruit overripe when picked scalded the worst; and fruit picked very green scalded worse than that properly matured when harvested. Among the varieties that developed scald most seriously were Bartlett, Louise Bonne de Jersey, Beurré Clairgeau, and, to a less extent, Beurré Hardy; while among those developing the least scald were Easter Beurré and Beurré d'Anjou.

Wilting in storage is rather serious with some varieties such as Beurré Hardy, Beurré Bosc, Doyenne du Comice, Winter Nelis, Easter Beurré, and Beurré d'Anjou, particularly with fruit harvested green.

In the experience of Overholser and Latimer, the maximum storage periods at 32° F. for some of the varieties studied were as follows: for Lawrence 223; Winter Nelis 215; Easter Beurré 205; Beurré d'Anjou 197; Beurré Bosc 164; Beurré Clairgeau 161; Kieffer 203; Doyenne du Comice 161; Flemish Beauty 150; Beurré Hardy 133; Bartlett 116; Seckel 123; Clapps Favorite 110; and Howell 111 days. However, while the fruit when taken out was in such a condition that with a brief period at a higher temperature it was of good quality, it could hardly have been shipped and marketed. In fact, it is probable that much of it could not have been marketed without loss in the average retail store even if taken there directly from storage without the necessity of shipping. The period during which the fruit could be stored before or after shipping to a distant market would probably be less than half the number of days given for the more tender varieties and at least thirty to fifty days less than that given for the more durable ones.

When tender perishable varieties are to be shipped and marketed in distant cities or when durable varieties are to be shipped to such a market and held for a considerable period in storage, precooling may be necessary. Magness (1284) says that in districts where the fruit is of such a nature that it reaches the desired market without loss, the expense of precooling may not be justified; but it has been found desirable in some of the sections with rather cool summers. He says that pears cool slowly; and it will generally require twenty-four hours to cool unwrapped fruit in lug boxes to 28° F. even in rooms where the air temperature is kept considerably lower than that. A much longer time is required with wrapped fruit in packed boxes. For this reason best results in precooling seem to be obtained if the fruit is cooled before packing; provided there is available a cool room (about 40° F.) in which to pack it.

The best handling practices are more important with pears that are to be kept for long periods in storage or shipped long distances than for apples. Thus, a larger percentage of storage pears may profitably be kept in small packages such as the bushel box. Since pears ripen faster than apples, the slow cooling toward the center of large packages is more harmful; and, since ripe pears are softer than apples, the heavy mass of fruit pressing upon that in the lower part of a large package causes more damage. For this last reason, wrapping may be more beneficial with pears than with apples; and, for both reasons, it may be more important that the storage temperature be kept as low as possible, that the fruit be hastened to storage, and, perhaps, that precooling be practiced. However, many of the pears that go to the market are not to be kept until near the storage limit; and so it does not follow that wrapping or packing in small packages is always profitable with pears. In the eastern part of the United States, since most varieties of pears are generally harvested late enough in autumn after the weather is cool and since the shipping distances are not great, expensive precautions in handling are generally not found profitable.

Shamel (1340) and Taylor and Overholser (1359) found that Bartlett pears stored at temperatures above 85° F. were delayed in ripening. Fruit stored at 104° F. was two to three weeks later in ripening than that stored at 85° F. This seems to have no practical importance since fruit so stored was low in quality. However, it is suggested as an explanation of a later ripening than might be expected in some very hot sections.

Handling the quince. Little study has been given to the handling of the quince, probably because, being a preserving fruit only, there is little occasion to hold it in storage and, being of rather good keeping quality, it withstands shipping through any practical distance. However, it must be handled carefully to avoid bruising, since this shows on the surface very strikingly.

Handling peaches. More than with many other fruits, the quality of the peach is influenced by the degree of ripeness it acquires on the tree. Yet, since it becomes ripe and breaks down rapidly, it must be picked green enough to reach the consumer before it deteriorates. When the fruit ripens in midsummer and must be shipped about a thousand miles, it is picked when the green color on the shaded side begins to fade into a pale yellow. In such sections, the fruit must be picked every day, only fruits in the right stage being picked. Where the fruit ripens in cooler weather and is not shipped so far, only two or three pickings are made.

The refrigerator car is indispensable for peaches, and in nearly all cases, if precooling rooms are not available, the cars should be pre-iced so the fruit will be cooled as quickly as possible. Methods of obtaining rapid cooling, such as using salt with the ice in the bunkers, will be desirable with the peach more often than with most other fruits except berries.

Cold storage is used with the peach only to carry it past gluts in the market. Powell and Fulton (1312) found that a temperature of 31° to 32° F. is better than any higher one. Hill (1264) from his experience with the injurious effect of excluding oxygen from stored fruit suggested that the brownish water-soaked appearance that stored peaches sometimes show may be due to the exclusion of oxygen; and he thought that a wrapper may be injurious by excluding oxygen. However, Powell and Fulton found the wrapper to prolong the storage life of the peach. They found also that the fruit kept in better condition in small closed boxes than in the open, six-basket carrier. A small package is necessary if the peach is to be stored until it is very ripe; for it is too soft to bear the weight of fruit in a large package. Of course, haste in getting the fruit to storage after picking is more important than with any less perishable fruit. Fruit well colored but not mellow kept best in storage. That which was mellow when stored deteriorated rapidly, and that which was not sufficiently mature to be well colored shriveled.

It is important that peaches be not stored too long. They break down rapidly after removal if kept in storage until ripe. Powell and Fulton found, with Elberta and some varieties a little more tender as grown in the reasonably humid climates of Connecticut and Georgia, that, when all the best storage practices are followed, peaches may be stored two weeks and have time to be sold and consumed without deterioration after removal. They are often stored longer; sometimes as much as five weeks. The storage limit of peaches is different for different varieties and different seasons and sections. It is probable that in sections where the weather is dry at harvest time and during the preceding three or four weeks it may be stored longer. Thus, most varieties of peaches grown in California tend to be very compact in texture, those grown for canning strikingly so; and at the University of California Overholser and others found that fruits of Elberta, Triumph, Yellow St. John, Muir, Wheatland, and a number of other varieties could be held five weeks at 32° F. without danger. Fruits of the Phillips Cling variety have retained good quality after eight weeks or more in storage. However, this is a canning variety, and peaches for canning are seldom stored longer than two weeks. If they become mellow before canning, the expense of removing the peel may be increased, and the liquid surrounding the peaches in the can may tend to become somewhat turbid.

Handling plums. There are so many species of plums that to generalize concerning their response to handling methods is not safe. However, of the three most important species, *Prunus domestica*, *Prunus salicina*, and *Prunus insititia*, the last is so resistant to rough handling that it need not be considered here. The varieties of the other two species are, when grown in a dry climate, perhaps, a little more durable in storage and shipping than most varieties of peaches.

Like the peach, most plums of these species are generally of very low quality unless they become nearly ripe on the tree. However, Ramsey (1323) found that Italian prunes picked about three weeks before they are normally harvested for drying were of much better quality after shipment than those picked at the time of picking for drying. This is not necessarily out of harmony with the responses of other plums; for prunes are generally harvested in a much more advanced stage of ripeness than could be permitted with any fruit that is to be marketed fresh. Diehl and Magness (1231) studied the ripening of Wickson (*Prunus salicina*) and Grand Duke (*Prunus domestica*) plums as grown in California. With eight pickings, ranging from June 23d to July 28th with Wickson and July 8th to August 14th with Grand Duke (the fruit being held after picking at 60° F.), by far the best quality was found in the later pickings; pickings considerably later than when most of the fruit is harvested commercially. They found a marked increase in dry weight and sugar content and a decrease in acid with these later pickings. Wickson is normally picked July 10th to 16th when it shows a light yellow color at the tip and Grand Duke about August 7th when it begins to have a purple cheek. Later pickings have more sugar, higher quality, and larger size.

The green picked plums ripened relatively more slowly after picking than would green picked fruit of other kinds. Thus, Wickson fruits picked July 3d required thirty-eight days to ripen at 60° F.; while those picked July 23d required but fifteen days to ripen. Grand Duke fruit picked July 28th required twenty-six days to ripen at 60° F.; while that picked August 7th required thirteen days.

Their results for one year indicated that, with these varieties, only fruit picked when nearly ripe can be held in cold storage. The fruit picked green is of lower quality when held at 30° or 32° F. than when held at 60° F. Fruit picked when nearly ripe was held at 32° F. four to six weeks before discoloration of the flesh around the pit began. Overholser (1303) studied the behavior in storage of a large number of varieties of plums grown in California. Wickson, Kelsey, Satsuma, Climax, Tragedy, and Grand Duke could be kept well in storage at 32° F. nine to eleven weeks; while Yellow Egg, Sultan, Beauty, Agen, and Sugar could be kept six weeks, and after being removed from storage were in good condition five to eight days. Abundance, Burbank, Imperial Epineuse, Combination, Clyman, Robe de Sergeant, German Prune, Pond, and Peach could be kept four to five weeks; while Washington and Columbia could not be kept well longer than two to three weeks. Climax and Tragedy developed the best flavor in storage. Combination, Peach, Columbia, and German Prune developed very low quality in storage. While the fruit kept best at 32° F., he thinks that Kelsey, Wickson, Agen, Grand Duke, Satsuma, Yellow Egg, Pond, Climax, Tragedy, Robe de Sergeant, and Beauty keep well enough at 36° F. to be shipped safely in refrigerator boats through Panama from California to Atlantic Coast markets, provided the fruit is hastened into the low temperature after being picked.

Overholser (1304) stresses the fact that if picking is delayed longer than in common practice in California, fruit of larger size with a higher sugar content and better quality will be obtained. Diehl and Magness (1231) emphasize this view also but qualify it with the statement that while the more mature fruit keeps the better at 32° F., the less mature fruit keeps much the better at 60° F. and that it will undoubtedly carry through the markets with less danger of loss to the shipper. The more mature the fruit when it is picked the more carefully it must be handled. The problem is always with the marketing organizations to determine what degree of ripeness with the resultant increased cost of handling will be repaid by the increased price of fruit reaching such a stage of ripeness.

In handling plums special precaution to avoid skin punctures or bruises is necessary in order to avoid injury from the rot fungi to which they are very susceptible. Ramsey (1323) found that Italian prunes could be shipped from the Willamette Valley, Oregon, to eastern markets if, besides rapid cooling of the fruit after picking and good refrigerator-car service, care were taken to avoid breaking the skin or removal of the bloom from the surface. Brooks and Fisher (1211) found that spraying or dusting greatly reduced the development of *Schlerotinia* in transportation, but did not influence the development of *Penicillium* or *Rhizopus.* The development of these in transportation is worse than in storage, since the lower temperature in storage greatly inhibits their development.

Handling apricots. Apricots are used largely for canning and preserving; and the best methods of handling for marketing fresh have not been studied extensively. With this fruit more strikingly than with the peach, and perhaps as strikingly as with any of the varieties of plums, a good flavor is not developed if the fruit is picked very green. Overholser, in some unpublished work, found apricots to keep fairly well if picked when "firm ripe" and placed at once at 32° F. All varieties held in storage showed reduced quality; but Tilton, Montgamet, and Lewis decreased in quality less than others. Tilton could be kept in rather good condition six to eight weeks, while Montgamet and Lewis could be kept four to five weeks. Smyrna, Blenheim, Royal, Reutier, and Peach could be safely kept only two weeks, and Hemskirke only one week. If some of these varieties are to be shipped long distances in refrigerator cars, they will be in more need of precooling and other careful handling practices than will most other fruits.

Handling cherries. Cherries are not generally held long in cold storage except for the holding of many sour cherries frozen. Overholser found the dark-fleshed sweet cherries to keep six weeks at a temperature of 28° F. The average variety would keep about four weeks at 32° F., three weeks at 36° F., and two weeks at 45° F. Napoleon, Republican, and Black Tartarian kept better at 32° F. than did Lambert and Chapman. Carrick (1216) found Early Richmond and Montmorency sour cherries to be marketable after ten to fifteen days at 30° to 32° F., though some rot was developing. He found sour cherries more resistant to freezing than were other stone fruits.

The important consideration in handling cherries for the fresh fruit market is in transportation. Nearly all cherries are susceptible to brown rot and the sweet cherry is very susceptible. This can be largely held in check if the fruit is sprayed in the orchard. The other rots can be avoided only by having the temperature as low as possible, avoiding the bruises through which the organisms enter (Brooks and Fisher, 1211) and shipping no fruits with the stems off (Ramsey, 1323). The temperature in the refrigerator car can seldom be satisfactorily low; and of course after the fruit is removed from the car the temperature is higher. With sweet cherries that are to be shipped from the Pacific Coast, precooling the fruit, or exceptional care in pre-icing the car, seems especially desirable if the fruit is to be permitted to reach a desirable state of maturity before it is harvested. The fruit may suffer bruises in transportation and thus become very susceptible to rots. Hawkins and Sando (1261) found that the skin of Montmorency cherry requires considerably more pressure to break it at low than at high temperature.

Sour cherries for the fresh fruit market are picked with the stem, while for the canning factory they are generally picked without the stem. Sour cherries are generally suitable for use two weeks or more before they must be picked to avoid loss from overripeness. The quality is much better when picked in the later stages of ripening.

Handling strawberries, raspberries, blackberries, gooseberries, currants, and blueberries. The strawberry ripens even more rapidly than the peach. The surface is easily bruised, permitting the entrance of fungi, and the fruit always ripens in rather hot weather. Yet it has become a very important commercial fruit and is shipped great distances. There is much difference among varieties as to their resistance to handling methods. It is mainly the firmer fleshed varieties that are shipped great distances. Hawkins and Sando (1261) have shown that when strawberries as well as raspberries and blackberries are cooled to a temperature of about 60° F. the resistance to puncture or bruising is much greater than before cooling when the temperature was about 80° to 86° F. This emphasizes the importance of rapid cooling after picking; and is in agreement with the work of Stevens and Wilcox (1347) who showed that picking the fruit in the cool portion of the day reduced the loss from *Rhizopus* rot. These workers found also that washing strawberries reduces such loss. When strawberries are to be shipped to rather distant markets they must be picked often enough to avoid the presence of overripe berries. They must also be hastened to the shipping point and if precooling is not feasible (and unless a refrigerator plant is available for other purposes, separate precooling will generally be too expensive) must be placed in pre-iced cars and hastened to market. Only a few days can lapse between picking and consumption, unless they are placed in cold storage; and their storage range is short. Fulton (1245) found that strawberries grown under favorable conditions, handled carefully and stored at once after picking may be held at 30° to 32° F. one to two weeks. Of course, if they must spend a day or two *en route* in refrigerator cars they can be stored for only a very few days. This may sometimes be enough to carry them past a glut in the market. When picked during a rainy period they may be worthless after only five or six days in storage, even when brought at once from the field to cold storage. Berries grown to large size on low moist soil are more perishable than others.

The red raspberry is even more perishable and susceptible to rots than is the strawberry, while some varieties of black raspberries such as Gregg are more resistant than strawberries. The blackberry is not widely grown for shipping because the flavor is very poor unless it becomes so ripe that it is very soft; and because it acquires an unattractive reddish gloss in refrigerator cars or in storage. Some of the varieties grown in the Pacific Coast region, such as Mammoth and Himalaya, retain their color and quality more satisfactorily. Fulton found the best temperature for storing raspberries, blackberries, and strawberries to be the lowest possible, 32° F. or slightly lower. Red raspberries he found to keep two to three days, black raspberries three to five days, blackberries and dewberries seven to ten days, currants two to three weeks, and cranberries all winter. Strawberries, raspberries, and blackberries that have been stored several days will begin to break down usually in ten to twelve hours after removal. Strawberries and red raspberries next to the sour cherry are among the best fruits to be held at a temperature of –5° to 15° F. and used immediately upon thawing.

Carrick (1216) found Downing gooseberries to keep in good condition about twenty-two days at 32° F. and blueberries to keep in good marketable condition thirty days or a little longer. Blueberries were found to be excellent for holding at –5° to 15° F.

Handling cranberries. This fruit is much less perishable than other small fruits; and so the shipping problems are less difficult. While Fulton found they would keep in storage all winter, Morse and Jones (1295) found a rather large percentage of them unsound by February when stored at 32° to 33° F. They found, as would be expected, a reduction in sugar during storage, and that, without ventilation during storage, the berries will become soft, "asphyxiated." Shear *et al.* (1342) found better keeping in ventilated packages than in the barrels in which they are generally packed.

Some growers in Wisconsin flood their bogs and rake the berries off as they float on the surface. Stevens and Bergman (1345) found that this practice was less harmful if the water was cool and had a high oxygen content and if the berries were dried as quickly as possible, but that, with the best practice possible, the keeping quality was inferior to that of berries harvested dry.

Cull cranberries may be frozen as with sour cherries and other small fruits, thus preventing deterioration.

Handling grapes. Grapes of the species *Vitis labrusca* present little difficulty as to transportation. They are less perishable than strawberries or peaches. In fact, it is probable that they may withstand nearly as much exposure to outside temperature after picking as McIntosh or Wealthy apples.

While the fruit stands well at room temperature, experience indicates that fruit, of the varieties of this species generally grown, does not keep well in cold storage. It seems to wilt badly, the berries part from the stem and, according to Carrick (1216), the sugar seems to accumulate just beneath the skin, leaving the pulp very watery and insipid. He found, with Concord, that the fruit does not retain desirable quality more than three or four weeks in storage at 32° F. It is possible that a higher temperature would be better or that some other varieties might keep better. Hedrick *et al.* (162) say that fruit of Barry and Catawba will keep until March in good cellar storage. He lists other varieties as keeping nearly that late. Catawba and Vergennes are said by Cooper (1224) to keep in cold storage better than Concord. Thayer (1362) studied the storage of some varieties of Labrusca grapes grown in northern Ohio. He did not try Barry or Concord, and Catawba did not ripen well in his section. Wilder and Lindley kept in the best condition and Agawam, Diana, Gaertner, Salem, and Vergennes kept well. With most varieties the berries tended to part from the stem badly. He considers 40° F. near the most desirable temperature. Lower temperatures seemed to increase the tendency to part from the stem. A comprehensive study of the best storage temperatures for Labrusca grapes and the varieties that keep best in storage might be of great value. It is possible that only varieties such as Barry, Agawam, and Lindley having Vinifera strains in them, can be expected to keep in storage.

While Labrusca grapes do not seem to retain their quality at 32° F., they keep their quality for cooking purposes when frozen at 0° F. Grape juice made from grapes frozen to that temperature and kept for indefinite periods is said to be indistinguishable from juice preserved from fresh grapes. Of course, like all frozen fruits, it must be preserved or used at once upon thawing.

Many varieties of Vinifera grapes lend themselves more readily to storage. Stubenrauch and Mann (1355) studied the storage and transportation of California table grapes. They found 32° F. better than a higher temperature. The storage of these grapes was not found entirely satisfactory when they were shipped in ventilated crates. Table grapes from Spain are shipped in barrels with the spaces between the grapes filled with ground cork. In this way they withstand shipping and keep better than in crates. Since the expense of the cork in California would be prohibitive other materials were tried as fillers. All except redwood sawdust injured the quality in some way. This substance was found even better than cork. They found that when the grapes were carefully packed, cooled at once, shipped in refrigerator cars and placed in storage at 32° F. as soon as they arrived in New York or other marketing center the varieties listed in Table 83 could be expected to keep until the dates indicated.

TABLE 83. PACKING AND STORAGE SEASONS OF THE PRINCIPAL VARIETIES OF CALIFORNIA TABLE GRAPES WHEN PACKED IN REDWOOD SAWDUST AND STORED AT 32° F., SHOWING THE APPROXIMATE EXTREME LIMIT OF STORAGE

VARIETY	PACKING SEASON	APPROXIMATE DATE WHEN 5 PER CENT OF DETERIORATION DEVELOPED	APPROXIMATE EXTREME COMMERCIAL LIMIT OF STORAGE
Almeria (Ohanez)	Oct. 10 to 25	Jan. 1 to 15	Feb. 15 to Apr. 1
Cornichon	Oct. 2 to 15	Dec. 1 to 20	Jan. 1 to Feb. 1
Emperor	Oct. 15 to 25	Dec. 15	Jan. 10 to 31
Ferrara	Oct. 10 to 15	Dec. 15	Jan. 15
Malaga	Aug. 25 to Sept. 20	Nov. 1 to 10	Dec. 1 to 15
Muscat	Sept. 1 to 15	Oct. 1 to 15	Nov. 15 to 25
Pizzutello	Sept. 15 to Oct. 10	Oct. 15 to 31	Nov. 15 to 30
Flame Tokay	Sept. 25 to Oct. 25	Nov. 20 to Dec. 10	Dec. 1 to Jan. 1
Verdal	Oct. 10 to 15	Dec. 1	Dec. 20 to Jan. 10

Almeria grapes are not grown for shipment in California, but these workers think they could be kept until April 1st. They found that shipping in ventilated instead of iced cars reduced the length of the possible storage period. In Table 84 is given a summary of their experiences in storing a number of varieties.

Carrick (1216) found that Emperor will not freeze at 24° to 27° F. and can be safely stored at 28.5° F. or lower, thus reducing respiration about forty per cent. At this temperature grapes were kept without serious loss until April 1st. The method of packing in redwood or other sawdust is expensive, and it does not seem very promising except for varieties that will command a high price. It is probable that even with Emperor, much of the crop will continue to be packed in crates; only a part of the

Table 84. Results of the California Grape-Storage Experiments during the Season of 1906 to 1911 Inclusive, Showing the Minimum and Maximum Number of Days the Principal Varieties were Held at 32° F. before 5 per cent and 15 per cent of Deterioration Appeared

Varieties	Method of Packing and Percentage of Deterioration					
	Redwood sawdust[a]		Granulated cork		Commercial crates without a filler	
	5 per cent (days)	15 per cent (days)	5 per cent (days)	15 per cent (days)	5 per cent (days)	15 per cent (days)
Almeria (Ohanez)...	70 to 155	150 to 285	90 to 120	120 to 175	55 to 70	80 to 110
Cornichon.........	50 to 85	70 to 150	75 to 80	100 to 140	20	45 to 60
Emperor...........	80 to 120	95 to 180	65 to 80	90 to 105	35	60
Ferrara............	140	160	80	90 to 95	35	45 to 60
Malaga............	50 to 80	105 to 120	5 to 60	20 to 115	40	35 to 85
Muscat............	8 to 75	24 to 110	5 to 60	15 to 110	5 to 30	20 to 65
Pizzutello..........	30 to 65	70 to 110	20 to 55	55 to 90	10 to 30	30 to 50
Flame Tokay.......	45 to 60	80 to 120	35 to 50	60 to 100	45	60
Verdal.............	55	95 to 130	60	90 to 110	5	15 to 25

[a] Later, as good results have been obtained with spruce sawdust as with redwood sawdust.

best fruit being packed in redwood or other sawdust to be held for the Christmas trade or later.

Handling citrus fruits. It is the intention here not to discuss all of the details of handling citrus fruits, but to discuss only some of the problems growing out of the physiological nature of the fruit. The citrus fruits are very susceptible to the growth of certain fungi. Powell (1314) and his associates found that the large losses from this source could nearly all be avoided if in picking, washing, grading, and packing, great care was exercised to avoid puncturing or even scratching the skin. Many punctures were made by the shears used in cutting the fruit from the trees. Long stems left by some pickers caused scratches or punctures. Dropping the fruit in grading and packing also caused injuries sufficient for the entrance of fungi. The skin of citrus fruit when it is on the tree or when first picked is very easily injured because all of the cells in the rough surface are turgid. After there has been a considerable amount of wilting of the skin it is not so easily injured.

Perhaps on account of the predominance of the Navel orange in California, the supply of ripening oranges is not evenly distributed throughout the year and the price from early winter to a little past the holiday season is generally better than later. There is, therefore, a tendency to pick the fruit green before the holiday season, some varieties being colored by exposure to high temperature. This process of causing the yellow color to develop by exposure to high temperature is called "sweating" and is sometimes legitimate since some varieties have a green color when at the best edible condition. Lopez Dominguez (1281) could detect by chemical analyses no influence of sweating at 90° to 95° F. on the changes in sugar and other constituents of grapefruits during a storage period following. With fruit sweated and not sweated, the principal changes during storage were inversion of sucrose and loss in weight. He does not say what the storage temperature was. Such high temperatures are not now generally used with lemons, since Sievers and True (1339a) seemed to find that the loss of green color and the unmasking of the yellow is due less to the heat than to the effect on the chlorophyll of the gas given off from the kerosene heaters used. Wright (1382) has described a method by which Satsuma oranges having but five per cent of yellow surface may be colored yellow in four days or a little more. This is accomplished by placing the fruit in chambers into which is driven the exhaust gas from a gasoline engine or the gas resulting from incomplete combustion of kerosene. Such coloring is particularly desirable with Satsuma fruit which, on the tree, often begins to deteriorate in quality before the skin becomes yellow. By such coloring Alabama grown Satsuma oranges can be placed in the market before early winter varieties from Florida reach the market in large quantities. Chace and Denny (1216a) found that lemons and oranges can be colored apparently very satisfactorily by liberating ethylene gas in rooms containing the fruit. They had not been able positively to identify ethylene among the gases from the kerosene stoves used in sweating. Lemons would color satisfactorily at 60° to 65° F. but would color more rapidly at 70° to 80° F. At 90° F. the coloring was slower. Oranges would not color well at a temperature below 70° to 75° F.

Fruit picked green does not ripen to a good quality, but remains very sour. Since the sugar-acid ratio is so largely the determining feature in the flavor of oranges it is possible with some efficiency to regulate by law or official ruling the picking of oranges. One State has passed a law prohibiting the shipment of fruit containing more than 1.3 per cent of acid. In other sections both sugar and acid content tend to be high and a statement of the allowable amount of acid relative to the amount of other solids in the juice seems more widely applicable. The ratio of eight parts or more of other solids in the juice to one of acid calculated as citric acid without water of crystallization has been established for some sections. Official rulings have tended to prevent the excessively early picking of oranges.

Oranges and grapefruit are shipped in iced cars except when the weather is cold enough to make this unnecessary. And, at some shipping points, large precooling plants have been established. Much the larger percentage of the lemon crop is shipped without ice. While the citrus fruits, if the skin is sound, are rather durable at high temperatures, as compared with some of the more perishable varieties of apples; they cannot be kept long periods of time in cold storage. Thus, a tender apple like McIntosh or Twenty Ounce might not withstand as much exposure to the temperature of a store window as the orange, but would keep much longer in cold storage. Ramsey (1322) says citrus fruits should not be stored at a temperature of 32° F., but the best storage temperature for the oranges is about 38° F. to 42° F.; for the lemon about 42° F., and for the grapefruit about 45° to 50° F. And at these temperatures the storage period is but a month or two. The orange takes on a brown stain in storage and all citrus fruits are subject to a pitting or spotting of the skin thought by him to be due to the attacks of the fungus *Colletotrichum*, which, Ramsay says, develops worse at 32° F. than at the higher temperatures.

However, Hawkins, and Magness (1260) and Hawkins (1259) find that with the grapefruit loss from micro-organisms is much less while stored at 32° F. They find, too, that when the grapefruit is stored at high temperatures the amount of acid increases slightly, while at 32° F. the percentage of acid decreases considerably. In other words, the fruit becomes sweeter when stored at 32° F. It also seems slightly less bitter and the flavor is better. Further, except for the pitting of the skin, the fruit keeps considerably longer than at higher temperatures, being in good condition for six months. At temperatures above 40° F. the pitting does not develop. Hawkins cured the fruit at 70° F. for nine to forty-one days, then held it at 32° F. for periods of forty-nine to eighty-one days. His results lead him to think that the pitting may be due not to *Colletotrichum* but to a flattening out, without apparent disintegration, of the oil vesicles and the cells immediately surrounding them; and his preliminary studies suggest that the pitting can be reduced by curing at 70° F. for a period of about twenty-five or thirty days preceding storage. It does not seem impossible that means may yet be found of storing grapefruit and possibly oranges at 32° F. and keeping them during longer periods than fruits of either kind have been kept so far.

Lemons are picked from the same trees throughout the year; but the heaviest crops in California are in the spring. The greatest demand for them is in the hottest part of the summer. It is, therefore, necessary to hasten the ripening of those picked in late summer so as to get them onto the summer market, and to hold much of the spring fruit in storage for the summer market. The fruit is picked green when it reaches a size such that it fails to go through rings carried by the pickers. Fruit picked in late summer or autumn is generally sweated, or treated with ethylene, to hasten its yellowing, in order that it may be marketed before cold weather reduces the demand for lemons. That picked in winter or spring is held in storerooms where the temperature is kept as low as possible by ventilation, and an attempt is made to keep the humidity at about eighty per cent so there will be neither excessive wilting nor favorable conditions for the growth of rot organisms. According to Coit (1219) winter lemons are sometimes held in this way six or even eight months. Those picked after April 1st will not keep as long as those picked earlier.

Storage of some tropical and subtropical fruits. The banana, the most important tropical fruit, cannot be stored without injury at low temperatures. In fact, it seems to be injured by temperatures below about 50° to 55° F. It is generally held in transportation about 55° F. Good ventilation also is necessary. Ships used in the banana trade have very elaborate equipment for maintaining the temperature and for ventilation.

Wilcox and Hunn (1378) studied the storage of tropical fruits in Hawaii at temperatures of 32°, 36°, and 45° F. From their results they recommend for star-apples picking half ripe and curing two days in a well-ventilated room, then 32° F. for about three weeks. A longer period did not injure the flesh; but only discolored the skin.

They found several varieties of figs that kept one month at 32° F. without deterioration in appearance or flavor. For longer periods or at higher temperature fermentation began. Carrick (1216) found that in 1919 some commercial dealers in Los Angeles were holding figs at 28° to 30° F. in fifty-gallon barrels with one pound of sugar to two pounds of figs. Overholser and others seemed to find the fig an excellent fruit to hold frozen in sugar solution.

Wilcox and Hunn found that the papaya was not satisfactorily held in storage because of molds, neither was the strawberry guava. The mango held its flavor and appearance for about thirty-five days at 32° F. but not so long at 36° F. Pineapples kept better at 32° F. than at higher temperatures being in good condition except for a slight deadening of the color after forty-five days.

In Hawaii the avocado kept a little better at 32° than at 36° F. Fruits of the hard-shelled Guatemala type and of other varieties picked green and held at 32° F. for sixty days ripened to a good flavor in three days after removal. They held that flavor for six days. Fruits stored at 32°

F. when half ripe developed excellent flavor within two months without a ripening period at a higher temperature and showed no ill effects of storage. However, experience of some growers suggests that the avocado does not ripen evenly after having been held in cold storage. Perhaps different varieties do not behave alike in this regard or as to blackening of the skin which often occurs while the flesh is still in good condition. Overholser and others working at the University of California seemed to find 40° F. the best temperature for the varieties of this fruit studied. Above 40° F. ripening was not sufficiently inhibited; while below that temperature wilting, blackening of the skin and browning of the flesh seemed to be hastened. Harvesting avocados rather immature seems to have less influence than with other fruits on the quality developed in storage or in the retail stores. In fact, it is not easy to determine when the fruit is in the best condition for harvesting. With the dark-colored varieties it is assumed that when the skin is fairly well colored the fruits may be picked. There is less certainty with the green varieties. There seems to be a period of several weeks during which, if the fruit is harvested, it will develop equally good flavor. Church and Chase (1218) studied the changes in composition of avocados during growth. They found a loss of sugar and an increase in fat as the fruit approaches maturity; but during a month or more at the end of the period the fat content increases little if any and may decrease. The sugar content of the ripe fruit is so small that it can have little if any influence on flavor. The outstanding constituent of this fruit is fat; and it seems that there is a period of considerably more than a month during which the fruit may be picked without influencing perceptibly its fat content. These workers could find no change in physical properties of the fruit that could be used in determining the best time for harvesting.

Some of the outstanding features in the handling of persimmons have been discussed in Chapter 25. Overholser in some unpublished work found that the varieties Hachiya, Tamopan, Fuyu, Mamegaki and Shakumi could be kept in storage at 32° F. about two months without much if any injury to the quality. With the variety Gosho, his results were in agreement with those of Gore in that keeping in carbon dioxide five days removed the astringency very satisfactorily but slightly hastened the ripening and breaking-down process.

CHAPTER 27

THE IMPORTANCE OF VARIETAL DIFFERENCES AND THE MAINTENANCE OF VARIETY STANDARDS

In the preceding chapters have been discussed many problems as to the influencing of orcharding practices on the growth and fruitfulness of trees and on the size, color, and quality of fruits. The greatest stress has not necessarily been given to problems concerning practices of the most importance in profitable orcharding. The amount of stress given to a problem has been determined more largely by the amount of work bearing upon it that has been done by scientists than by the economic importance of the problem. Perhaps the most important problems as influencing the grower's profits are concerned with insect and disease control. Such problems have not been discussed because they concern the nature and responses of the insects, fungi, or other organisms causing the injuries, to a greater extent than they concern the nature and responses of the trees. Critical treatment of such problems can be effective only by persons having broad acquaintance with the literature of entomology and plant pathology.

Another feature of great economic importance is concerned with differences in fruiting of varieties of the same kind of fruit. Market opportunities or wide differences in the nature of the soil as to drainage, texture, aeration and nutrient supply may influence the grower's profits more than will his choice of varieties; so may large differences in the soil water supply, or climatic features, such as frequency of killing freezes after the blooms have opened, or winter temperatures low enough to kill the wood or the fruit buds. Unwise orcharding practices, such as growing the trees in sod without supplying available nitrogen, and perhaps in some climates excessive or insufficient pruning, may be more disastrous economically than unwise choice of varieties. However, differences in practices that will cause such large difference in results will fairly soon come to be well understood by the growers. Practices concerning which the better growers are long in disagreement, and which, therefore, present problems, seem generally to be of less economic significance than are possible differences in varieties chosen. The economic importance of wise selection of varieties is illustrated by the results of Thompson and Miller (328, 329) and Miller and Thompson (1082, 1083). They found that in the Hood River Valley, Oregon, the average yield of trees in full bearing was perhaps two thirds of that in the Payette Valley, Idaho; about half that in the Yakima Valley, Washington, and probably less than half that in the Wenatchee Valley, Washington. They think that a large part of the difference in yield is due to differences in varieties grown. We have much need for more conclusive information as to the response of fruit trees, as compared with other crops, to applications of potassium; yet we can be certain that there are few soils in the United States in which applications of potassium will cause an increase in yield that is nearly as great as the differences in yield among some varieties of the same kind of fruit grown under the same conditions. In Chapter 24 it was shown that much of the wide distribution of any kind of fruits was due to differences in variety response. While the adaptation of a kind of fruit to different climatic features can be influenced by cultural practices, particularly pruning, selection of adapted varieties is by far the most important means of such adjustment. Thus, varieties of apples that in other sections have a fairly tender flesh may have, in some Pacific Coast sections, a somewhat unpleasantly firm flesh. Yet, in such Pacific Coast sections, some varieties such as Skinner Seedling have a very pleasant, tender flesh. It is probable that there may be developed for such sections varieties of which the fruit has a flesh as tender as marketing requirements will permit.

While there are now many varieties from which to select for adaptation to different soil, climatic, and marketing requirements, there are few, if any, sections in which the best available varieties do not have some rather serious defects. In a few cases, such as that of Winesap in some of the fruit-growing sections of Washington, the adaptation is so nearly satisfactory that the prospect of improvement does not seem very promising. However, in most sections it should be possible to develop varieties considerably more desirable. By far the larger number of varieties grown in the United States have been obtained from seedling trees not grown with the purpose of producing new varieties. The large number of such varieties is explained by the fact that in some sections there were considerable periods during which many of the farm orchards were of seedling trees. There has also been much waste land on which chance seedlings might grow. For these reasons many seedling trees have been available among which promising varieties might be selected. Seedling orchards are no longer grown; injurious insects and fruit-tree diseases have been so thoroughly disseminated that a chance seedling on waste land has little opportunity to bear sound fruit; and in some of the most important fruit-growing sections lack of water prevents fruit trees from growing in waste land; it seems probable, therefore, that further variety improvement except by planned fruit breeding will be very slow.

It is the purpose here not to enter into a discussion of the principles of plant breeding, but merely to indicate briefly some of the general developments in fruit variety improvement. There has been conducted in the United States a rather large amount of fruit breeding. However, with most of the tree fruits, very few of the varieties that have come to be widely planted have been obtained through such breeding. This would be expected since the method of breeding used (where any method was used other than the mere planting of seeds of which only the pistillate parent was known) has been a growing of seedlings from crosses between varieties having desirable characteristics. Probably a considerable percentage, if not a very large percentage of the chance seedlings, were from natural crosses between such varieties. There have been many more chance seedlings than seedlings from hand pollinations; the opportunity for obtaining desirable varieties has therefore been greater through the chance seedlings. Probably the varieties that have been thus selected have desirable characteristics to so much greater extent than is characteristic of the species or strain to which the varieties belong that only a very small percentage of seedlings from crosses between such varieties will possess enough of the excellent qualities of either variety to make the seedlings desirable; even though some of the desirable characters of both parent varieties were found in the seedlings. For example, if McIntosh and Green Newtown apples were crossed for the purpose of obtaining longer keeping fruits with the characters of McIntosh, many of the seedlings might have the long keeping character of Green Newtown combined with some of the characters of McIntosh; but, certainly very few would be equal to either parent in general excellence of qualities.

With the strawberry a considerable number of leading varieties have been obtained from controlled pollinations; and a considerable number of others have been obtained by planting the seed of fruit from uncontrolled pollinations. In other words, a large number of the varieties of strawberries have been obtained through plant breeding. This would be expected; for the plant breeder can easily grow large numbers of seedling strawberry plants from which to select desirable varieties; there is less opportunity with strawberry plants than with tree fruits for chance seedlings to be found, and seedling strawberry plantings would be grown only for breeding. In other words, plant breeding can proceed much more rapidly with small plants like the strawberry; and, with the strawberry, there has been less competition with chance production of desirable seedlings.

With most other fruits the promising production of new varieties through plant breeding has been mainly in sections where climatic conditions are unfavorable for the growth of the older strains. In such sections, there has been less opportunity for the chance growth of valuable seedlings; and desirable varieties have been obtained by crossing resistant kinds with varieties of higher quality that may be less resistant. Thus, Hansen and Macoun have introduced a considerable number of varieties more resistant than older varieties to the severe climate of the Dakotas and that of some sections of Canada. And some resistant varieties are being introduced from the fruit-breeding farm of the University of Minnesota; such as the Zumbra Cherry said to combine the high quality of the sweet cherry, one of the strains in its development, with the resistance to low temperature of the Sand cherry also used in its development. We have seen in Chapter 24 that, with the apple, the breeding of late blooming varieties for sections where there are late spring freezes seems very promising. In this kind of breeding also there is less competition with chance production of new varieties; for there has been little opportunity for chance crossing of early blooming varieties, that produce desirable fruit, with late blooming varieties.

Because it is difficult to grow the plants in sufficient numbers, not much that could be classed as principles has been learned concerning the mode of inheritance of characters with the different kinds of fruits. However, some helpful knowledge of an empirical nature has been gained. Thus, while few of the seedlings of a variety will equal the variety in general excellence, a considerable percentage of them will resemble it in many characters, and in crossing one can be reasonably certain that some of the characteristics of the varieties used will show in the progeny. Cummings and Jenkins (91) could trace variety characters, such as flavor, position of the seeds and nature of the core, through several generations of the progeny of a variety of strawberries. With the tree fruits, while there have not generally been in the experiments sufficient numbers to warrant general conclusions, it seems that some varieties are much more effective than others in transmitting their striking characteristics. Ben Davis, Delicious, McIntosh, and Fameuse apples seem to be of that class. Macoun (229) obtained promising results in breeding for a hardy long keeping variety by crossing McIntosh and Lawver. He reports good results also from Shiawassee, which like McIntosh is a seedling of Fameuse. Wellington (354) reports very promising results when McIntosh or Delicious were used in crossing. The late blooming character of Ralls seems to be generally transmitted when used in crossing with early blooming varieties of better quality. Tukey (336) has emphasized the fact that nearly all the varieties of grapes of American origin having very high quality have been the result of crosses between the American species and varieties of *Vitis vinifera*.

Macoun found that in crossing very hardy varieties with desirable but less hardy varieties he always obtained seedlings less resistant than the hardy parent. In other words, it is not possible in the first (F_1) generation to obtain a combination of the long keeping qualities of Baldwin fruit with the hardiness of wood of certain Russian varieties. From what is known as to Mendelian inheritance it would be expected that there would be a greater opportunity of obtaining such a combination in the F_2 generation — (seedlings from self-pollinated flowers of the F_1 generation). However, there is no certainty that it could be found among the relatively small number of F_2 seedlings that could be grown.

While knowledge of the principles of genetics must be of great service in fruit breeding and special knowledge of the modes of inheritance of desirable characters of the different kinds of fruit will be very helpful if it can be obtained, it seems to me that the most nearly indispensable equipment for successful breeding of varieties to meet the problems of to-day is comprehensive and detailed knowledge of the species and varieties of fruits; the obscure ones as well as the others. Many varieties, such as Ralls, that may be almost worthless in themselves may be the most important as a source of some valuable character which, in breeding, may be combined with the high quality or other valuable characteristic of some other variety.

Influence of bud variation on the yield of trees of a variety. The selection of new varieties of fruit is rendered somewhat more simple by their being propagated vegetatively. It is not necessary to isolate pure strains. Many think, however, that there is often enough bud variation in a variety to render bud selection desirable. The nurseryman's method of obtaining scions from a scion orchard made up of trees that have never borne, generally young trees left over from a nursery, is often criticized. It is feared that by such a process there is danger of obtaining trees of a low bearing habit, or at least that the process may preclude the possibility of obtaining trees of the best bearing capacity for the variety. Some even maintain that by this method the varieties may deteriorate because of the constant addition of degenerate strains. They advocate the practice of selecting scions only from bearing trees whose records are known to be good.

Bud variations do occur. Several new varieties of fruit are known to have originated as "bud sports," and many more varieties of ornamental plants have so originated. These fruit varieties have generally been selected for differences in the nature of the fruit; primarily differences in color. Such characters are of course much more easily detected than is high yielding capacity. Yet the number of bud mutations having strikingly different fruit from that borne by the parent variety must be small. At least the number of such mutations with which there is marked improvement in such fruit characters must be small; for Dorsey (106) has called attention to the fact that of 2664 varieties of apples (Beach *et al.* 43) grapes, plums, and cherries (Hedrick *et al.* 162 to 165) listed in the fruit books of the New York Agricultural Experimental Station, only five are thought to have originated as bud mutations; yet, during the time when most of these varieties were being introduced, very many more trees have been grown by asexual propagation than from seedlings and they were under more careful observation; it seems, therefore, that if striking bud mutations occurred rather frequently many more of the desirable varieties should have originated from such mutations.

However, if there had been among these many trees a considerable number of mutations with which the character of the fruit was not appreciably different from the variety, but with which the yielding capacity of the tree was considerably greater than that of normal trees of the variety, such mutations would probably not have been observed unless the bearing habit of the tree had been modified in such a way that the difference would be readily detected by casual observation. Mutations that have to do only with yielding capacity above or but a little below the normal, if such occur, would generally be detected only through careful yield records. And there is a very great danger that such records will be misleading. We have seen in the Introduction that Batchelor and Reed (2) found half or more of the variation in yield of apple trees, and of orange trees, due to variations in the soil; although the soil had been selected for uniformity. There are also variations in growth and yield due to variations in the stocks and due to special features such as restriction of roots resulting from their being crossed or twisted around each other in planting, injury to a branch, or starting a tree with too few branches. Sax and Gowan (301) describe productive and unproductive types of Ben Davis apple trees in a large experimental orchard in Maine. Of the unproductive trees about sixty-five per cent were grouped in certain areas, suggesting that their unproductiveness was due to the nature of the soil. Of the other thirty-five per cent, part must be low producing because of unfavorable root stocks and because of injuries of various kinds. It would certainly be impossible by means of production records to tell which of the trees among these thirty-five per cent are low yielding because of bud mutations and which because of unfavorable root stocks or because of injuries.

A few experiments have been conducted with the purpose of determining the importance of bud variation as influencing the yielding capacity of the trees of a variety. Whitten (358) and Gardner (141) have reported concerning the yield records of a few Ben Davis apple trees whose scions were taken from a Ben Davis apple tree that yielded well, and of a few whose scions were taken from a tree that for some reason did not yield well. The average yield of the trees from the low yielding parent during seven years was eighteen per cent greater than that of trees from the high yielding parent. The same authors report, without giving data, the results of an experiment with bud selections of strawberry plants. The experiment started with six high-yielding and six low-yielding plants. In each succeeding year there were selected six of the highest-yielding plants from the descendants of each of the original high-yielding plants and six of the lowest-yielding plants from the descendants of each of the original low-yielding plants. After ten generations had been grown, there was no evidence that the yield had been influenced by the selections. However, the land on which the plants were grown was variable, poorly drained, and unsuited for strawberry plants. Since many can be grown in a small area, strawberry plants should be very satisfactory for bud variation studies. On the other hand, they are very responsive to slight soil variations and generally give uncertain experimental results. Rawes (283) reports the results of the early fruiting of a considerable number of trees of several varieties, half of which were from parent trees that had yielded well and half from trees that had yielded poorly. In so far as the amount of fruit borne by the trees when just coming into bearing is indicative, the trees from low-yielding trees were as productive as those from high-yielding trees. Cummings (89a) reports results with 120 scions from a productive tree and 128 from an unproductive tree. At the end of ten years the scions from the unproductive trees were slightly, though not significantly, the more productive. On the other hand, Macoun and Davis found better yields by young apple trees from scions selected from high-yielding parents than by trees from scions from low-yielding parents. Seven trees of each kind were concerned. There was a weak growth and a high death rate among trees from the unproductive parents suggesting that a disease had been transmitted with the bud. Davis thinks that if the parent trees had been equally vigorous and healthy when the buds were taken there might not have been the difference in yield even though one of the parent trees may, for some reason, have been unproductive. If seventy-five per cent of the low-yielding trees in the orchard are low-yielding because of unfavorable soil conditions, weak or incompatible stocks and injuries of various kinds to the tree (and with most fruits the percentage is probably considerably larger than that), it is not surprising that with so few low-yielding parent trees none were found whose low-yielding was transmitted with the bud. Neither is it proof that low-yielding bud mutations do not occasionally occur. It merely suggests that bud mutation is not the most important cause of the existence of low-yielding trees in an orchard. East (112) and Whipple (357) found degenerate strains in varieties of potatoes, but no indication of mutation toward higher yielding. Neither considered that he found results that would justify seed-potato growers in keeping hill-yield records for the purpose of maintaining high-yielding capacity of his seed. It is probable that some of the apparently degenerate strains may have been due to diseases such as mosaic. These men grew very many plants; and since many plants can be grown on a rather small area and there is no stock problem, the results should be much more reliable than with trees.

Shamel *et al.* (305 to 314) have published extensive records of the yields of individual Washington Navel orange, Lisbon lemon, and Marsh grapefruit trees. They naturally found marked variation as to yield, and seemed to find low yield associated with certain types of fruit borne. Sax and Gowan (302) call attention to the fact that these data as published do not prove that there is variability in yield due to bud mutation. For, of the small percentage of variability that statistical analysis indicates is not due to environmental features, such as soil, it is not possible to determine how much is due to variations in stocks or to other unknown features, and how much, if any, to bud mutation, and they show that, at least with the lemon, there was more variation as to type of fruit borne by the high-yielding trees than by the others.

It is certain, however, that with some of the low-yielding strains, the low-yielding character is transmissible with the bud (Shamel *et al.* 310). At the *Citrus* experiment station at Riverside, California, there are large, nearly barren Washington Navel orange trees propagated from such trees. There are also trees bearing undesirable fruit, such as ribbed specimens, that were propagated from trees bearing such fruit. Some of these trees seem to be chimeras; and it seems possible that mixed buds from some original chimera have been widely disseminated. Such trees, whether chimeras or mutations, could be detected for top-working as well by means of systematic observation as by expensive yield records of individual trees. Hodgson (180) suggests that such simple observational tree behavior records be carried through enough years to determine fruitfulness of the wood of all the trees. He says that often the low-yielding citrus trees are found in groups, indicating an unfavorable soil area; sometimes soil treatment brings improvement. He says that sometimes top-working has failed to bring improvement. If a tree in unfavorable soil or one on a weak stock is top-worked, unless the invigorating effect of severe pruning brings a temporary fruitfulness, there will be wasted certainly the expense of doing the top-working, and if the low yield is due to the small size of the tree, about as large a crop being borne as the tree is capable of carrying, there will be also some loss due to the removal of fruiting wood in top-working. Of course, with such trees the top-working can hardly cause a final increase in yield. It seems that only trees such as the almost completely non-fruitful "shade trees" and trees bearing undesirable fruit should be top-worked. Trees of which the low yield is due to small size but which bear desirable fruit, should of course not be top-worked. In other words, observational records, such as Hodgson recommends, should give much more reliable information than would individual yield records.

In nursery propagation of fruits having as many undesirable bud variations as some *Citrus* varieties have, it may be that buds should be taken only from bearing trees and only from trees bearing good fruit regularly. It does not follow that they should be taken only from trees with which yield records have been kept. Shamel *et al.* say that the number of low-yielding *Citrus* trees is greater in the young Washington Navel orange orchards than in older ones, probably because the growers are inclined to take the scion wood from the unproductive trees since these grow more vigorously and good budding twigs are more easily obtained. In nurseries, where the scions are taken from small trees that have not borne, such a downward selection would hardly occur. In fact the small tree scion orchard should tend to maintain the standard of the variety very evenly unless bud sports that tend to reduce the standard of the variety are more numerous than those that tend to increase it. The nurseryman takes only a few scions from each of many small trees, these scions being much mixed in handling. When the young trees are dug and hauled to the sheds there is a further mixing. With all this mixing, the chance seems rather small that any one orchardist will get a large percentage of trees whose scions came from a tree of a degenerate strain. And, except with citrus fruits, orchard observation seldom suggests that a tree is unfruitful except because of some influence such as soil condition or stocks.

Selecting scions from trees with known records introduces difficulties and expense. The smallest of these is the extra expense of getting the scions. One of the greatest would be keeping the tree records. Another, with some kinds, is the poor growth that is made during the first year in the nursery, when the buds are taken from a bearing tree that ceases length growth early in the summer. The poor growth from such buds seems to result from the fact that, with the wood of the scions from bearing trees, cambial growth will have ceased before the budding on the nursery seedlings can be done (Fraser, 137, p. 35).

Summary. The difference in fruitfulness of varieties is rather great, and this difference constitutes one of the more important features in determining the profits of orcharding.

The bearing habit of most varieties of most fruits seems to be very permanent, bud mutation not being frequent enough to be of great importance. Some of the most fruitful varieties are very old. Variation in soil and other environmental features is so great that mutations as to yielding capacity alone can seldom, if ever, be detected by keeping yield records of the individual trees in an orchard; unless the yields are exceptionally small, as with "shade trees" in *Citrus*, when the low-yielding capacity can be as readily detected by means of annual observations as by means of more expensive annual yield measurements for individual trees. While scions should not be taken from trees that bear undesirable fruit or from trees that do not bear good crops for their size, there is no evidence that the yielding capacity of a variety can often be increased by selecting scions from trees having an especially high performance record as compared with the average trees in an orchard.

With some kinds, when budding is done in midsummer, late summer, or autumn, the trees make better growth in the nursery if the buds are taken from late growing young trees than if they are taken from bearing trees.

With some varieties of *Citrus* trees undesirable strains seem to be found often enough to make it unwise to take scions from trees that have not borne or from trees whose bearing has not been observed to be satisfactory during two or more consecutive years. However, with most kinds of fruits, the nurseryman's practice of taking his scions from young, vigorous, non-bearing trees is satisfactory, provided such young trees are known to be truly named. With a few varieties, even not of *Citrus*, bud mutation may be common enough to make it desirable to renew the scion orchard every fifteen or twenty years, using buds from trees known to bear well and to bear fruit with the desirable characteristics of the variety.

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